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# on station

The Newsletter of the Directorate of Manned Spaceflight and Microgravity

http://www.estec.esa.nl/spaceflight/

## in this issue



European Space Agency
Agence spatiale européenne

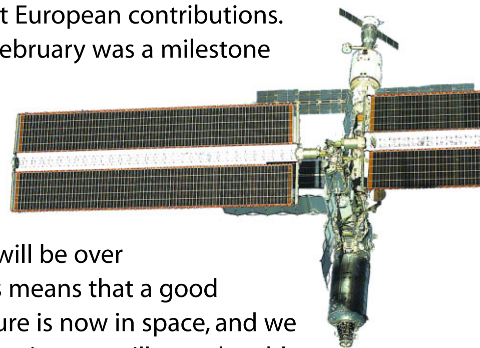
Directorate of Manned Spaceflight and Microgravity
Direction des Vols Habité et la Microgravité

## Planning the Future: A Year for Major Exploitation and Commercialisation Decisions

*Jörg Feustel-Büechl*
*ESA Director of Manned Spaceflight and Microgravity*

Last year went superbly well: eight launches to the International Space Station delivered long-awaited hardware and supplies. The hardware elements included Europe's first contribution, the DMS-R data management system, which is working well. We also had the first Expedition crew onboard – a real milestone for the Station and our overall partnership. The second crew recently took over the reins. I have firm hopes that this year will be as good as 2000.

There are up to 14 launches planned for this year, including some important European contributions. Destiny's appearance in February was a milestone in the Station's assembly because we now have the first real operational laboratory. Although it is not yet equipped with research facilities, it will be over the next few months. This means that a good portion of the infrastructure is now in space, and we expect that European investigators will soon be able to perform experiments onboard.



The most recent manned mission delivered the first MPLM, Leonardo, in March. Then, in April, we will have the first European – ESA Astronaut Umberto Guidoni - aboard the Station, along with the second MPLM, Raffaello. This year's highly ambitious schedule includes our second European astronaut, Claudie André-Deshays, who is manifested aboard a Soyuz taxi flight in October.

In a more 'earthly' sense, we completed the preliminary design review of our Automated Transfer Vehicle (ATV) on 14 December last year, and that was a technical success. We now have a consolidated design but are struggling with the financial consequences. On 18 January, the Columbus critical design review concluded – altogether very successful. We are now firmly on track with Columbus.

# ISS FORUM 2001

## INTERNATIONAL SPACE STATION

**ISS UTILISATION CONFERENCE ON:**

RESEARCH AND DEVELOPMENT

INDUSTRIAL APPLICATIONS

COMMERCIAL UTILISATION

**ISS is a programme of partnership**

NASDA NATIONAL SPACE DEVELOPMENT AGENCY OF JAPAN

# BERLIN

## 5 – 7 June 2001

*The International Space Station has established a new permanent human presence in space. With the arrival of its first research module, the ISS is now open for exploiting the assets offered by manned spaceflight.*

*In June, ISS FORUM 2001 will take place in Berlin to review the plans for exploiting the ISS and to brief everyone interested in the opportunities being opened up by this new infrastructure in space.*

*The European Space Agency – as one of the five Partners (NASA, Rosaviakosmos, ESA, NASDA, CSA) developing the Space Station – and the German Space Agency (DLR) invite all interested parties to this key event.*

*The ISS FORUM 2001 programme is supported by all the ISS Partners. It is designed so that participants from different sectors:*

- *understand the Station's unique potential*
- *capture available opportunities*
- *forge alliances for exploiting this new base in space*

**Honorary Programme Committee:**

| | |
|---|---|
| Dan Goldin | NASA Administrator |
| Yuri Koptev | Director General Rosaviakosmos |
| Antonio Rodotà | Director General ESA |
| Mac Evans | President CSA |
| Shuichiro Yamanouchi | President NASDA |
| Walter Kröll | President DLR |

Check the website at
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for further information and to register.

Presentations for this conference are by invitation only.

Questions and comments on the conference can also be addressed to
ISSForum2001@esa.int

The conference fee is EUR 300 / DM 600

The conference is supported by Lufthansa. Special fares to the conference on Lufthansa flights are available with the code GGAIRLHKONG.450

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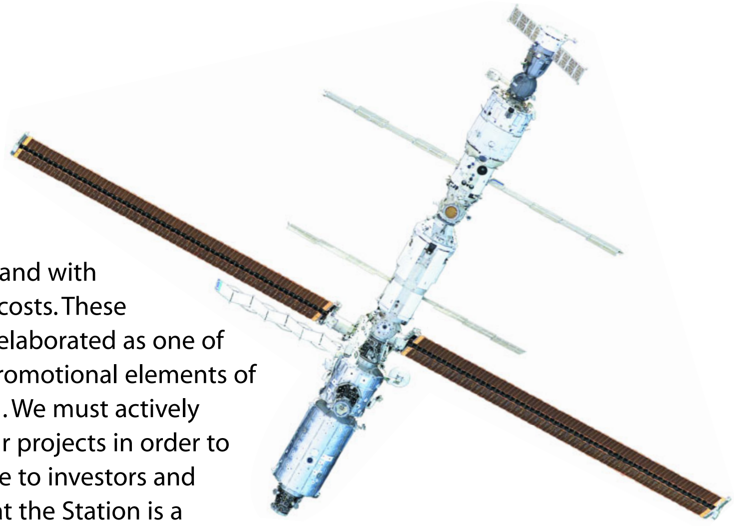
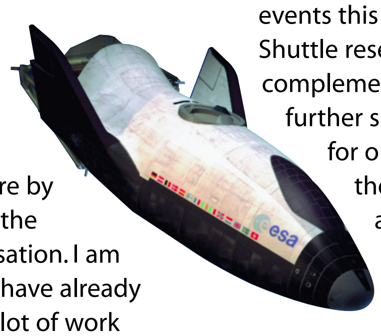


Of course, one of the significant highlights of 2001 is the Ministerial meeting in November. We are busy preparing decisions for the so-called Period 1 of the ISS Exploitation. This period covers the 5-year timeframe of 2002-2006, with approval of the first 3-year firm envelope and the following 2-year provisional envelope to be addressed. That will be a significant topic on the Ministerial agenda. In that context, we will have not only important decisions on operation of the Station, but also on its utilisation, and particularly on further efforts to promote commercial utilisation. We are preparing to promote commercial utilisation with a view to selecting a 'Business Developer' to take care of around a third of the European utilisation that has been earmarked for commercial applications. The other two-thirds are for institutional utilisation.

Indeed, commercial utilisation provides the major theme for the Forum 2001 in June in Berlin. This is where such questions as 'how to approach commercial entities', 'how to promote commercialisation', 'what needs to be done' and 'what resources are required' will be addressed. This is the first forum supporting all-Partner global commercialisation of the Station, demonstrating that we are able to offer such a potential capability. This is really a serious gesture by all five Partners to promote the concept of commercial utilisation. I am very pleased to say that we have already started the initiative, with a lot of work undertaken last year that has already led to some ideas for commercial utilisation.




We continue the vigorous pursuit of the process to find a commercial agent/Business Developer who will progressively take over more and more of the commercialisation issue. I firmly hope that we will be able to select such a Business Developer within the next 2 years. However, we need to firm up on our promotion programme before we can make that selection. The Station is still in its infancy and we need to convince potential commercial users that this is the way to go, with established rules and regulations that are practicable and with acceptable costs. These need to be elaborated as one of the initial promotional elements of Forum 2001. We must actively promote our projects in order to demonstrate to investors and industry that the Station is a worthwhile commercial venture.

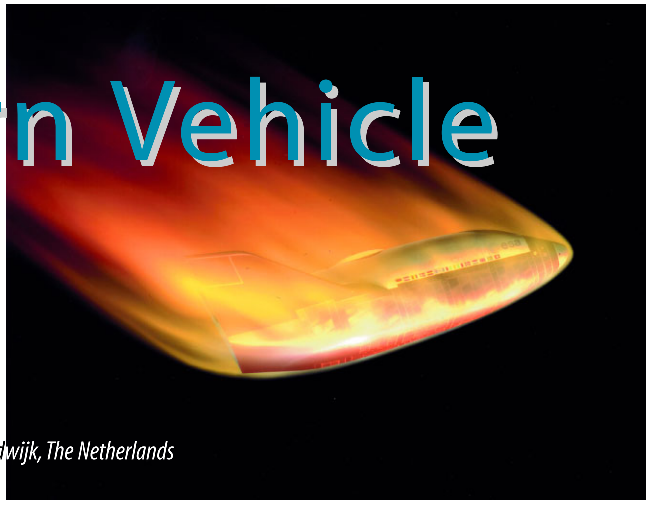
We should not forget that around two-thirds of the utilisation remains institutional and therefore available for scientific research either from ESA or our Member States. This is and will remain the backbone of our ISS utilisation programme. And there we have a number of early projects, including the ACES atomic clock experiment, solar science, Earth observation and technology experiments that are under development and that illustrate the scientific and technological utilisation in the broadest sense as well as being good opportunities onboard the Station.

We are looking forward to the STS-107 Spacehab mission where we have a lot of experiments totalling 580 kg onboard. We hope that it will be launched in September. STS-107 really is one of our key microgravity events this year. NASA aims to provide one Shuttle research mission per year to complement the Station, so we can expect further such scientific missions. We are keen for our microgravity community to use these flight opportunities and have already made some preliminary arrangements with NASA for the next opportunity.

ESA's DMS-R has been working fine since its launch last July. We certainly congratulate the industrial and ESA teams for their performance! I would also like to remind readers that this is an excellent example of Euro-Russo cooperation, and has turned out to be of great satisfaction for both parties.

As far as the Station's Crew Return Vehicle (CRV) is concerned, ESA is currently awaiting an industrial proposal for Phase 1, expected to be headed-up by a joint team from two industrial partners to lead the whole CRV industrial consortium. We are looking forward to placing a contract very soon, so that the implementation can begin in earnest.

# The Crew Return Vehicle



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*As the Space Station receives its first modules, NASA and ESA are on course to develop the next human spacecraft: the Crew Return Vehicle (CRV). The programme is building on the technologies and expanding the partnership developed in the X-38 programme...*

## Introduction

The CRV will return International Space Station (ISS) crews of up to seven astronauts safely to Earth in the event of a medical emergency, Station evacuation or if the Shuttle is not available. The CRV is the operational version of the X-38 prototype, which is being developed cooperatively by NASA, ESA, DLR and 22 European industrial firms in eight countries.

## CRV Mission Profile

Within 3 hours of departure from the Station, the Deorbit & Propulsion System (DPS) thrusters are fired to initiate the descent, and the module is jettisoned. The CRV enters the atmosphere at an altitude of about 120 km, travelling at 27 000 km/h. Attitude is controlled initially with cold-gas thrusters but, as air pressure increases, the rudders and body flaps take over. A drogue parachute deploys at 8 km altitude, stabilising the vehicle in a 1 *g* sustained sink rate. This is followed by the 5-stage deployment of the large 685 m$^2$ parafoil. Automatic guidance, navigation and control (GNC) software steers the CRV through its final descent and landing, with a safe forward speed of less than 10 m/s.

## ESA and the CRV

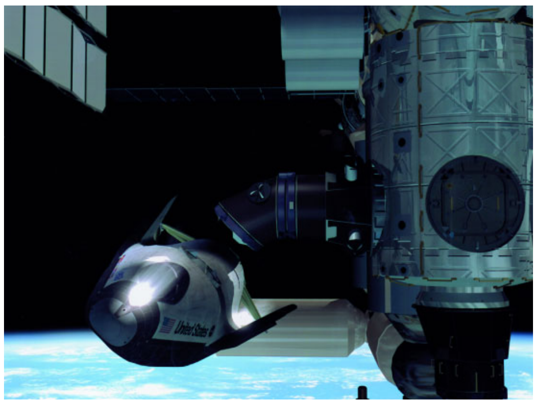
Building on the expertise developed in the X-38 programme, ESA and the European industrial team are now transitioning into the CRV programme. Europe brings a wealth of experience in reusable manned space systems and atmospheric reentry (see also the ARD article in this issue) to the programme.

CRV development is in two phases: Phase-1 includes the design activities up to the Critical Design Review; Phase-2 will include the production of four operational CRVs, two CRV/ISS berthing adapters, including the International Berthing/Docking Mechanism (IBDM), four DPSs and the provision of spares and sustaining engineering.

With the full start of Phase-1 in 2001, the first operational CRV is expected to be at the Station before mid-2007. Until then, astronauts will rely on Russian Soyuz capsules in emergencies.

Major milestones during the early part of Phase-1 are the System Requirements Review after 3 months, an Intermediate Design Review (IDR1) at 6 months, the Preliminary Design Review at 9 months, and the Safety Review and IDR2 at 12 months.

ESA began early Phase-1 activities in December 1999: aerodynamics and aerothermodynamics; qualification activities for the Ceramic Matrix Composite (CMC) material, for the hot structure body flaps, rudders and nosecap Thermal Protection System (TPS); display technique development and man-machine interfaces; design activities for the IBDM; and system and subsystem engineering

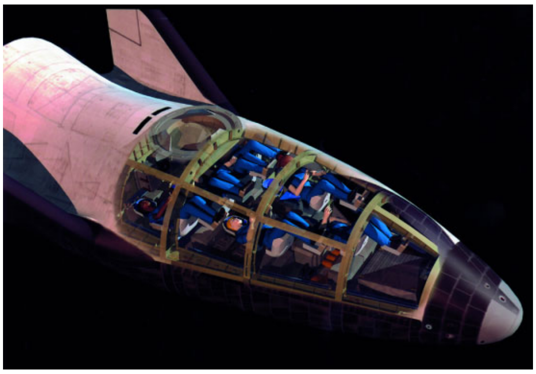


*The CRV departing from the Space Station. (NASA)* as part of the integrated ESA/NASA team at the Johnson Space Center (JSC) in Houston.

Since the programme began, Italy has confirmed its participation and Austria has joined as the 9th participant. Overall, countries have increased their contributions – allowing a larger ESA programme – and have vowed a further increase no later than at the end of Phase-1, in order to secure a European role throughout CRV's operational phase, including the provision of spares and sustaining engineering. Following the approval of the consolidated programme by ESA's Manned Space Programme Board in September 2000, the Request for Quotation was issued to industry in early October. The Phase-1 proposal, received in December, is being evaluated, with a view to starting the full Phase-1 in the second quarter of 2001, synchronised with NASA's industrial Phase-1.

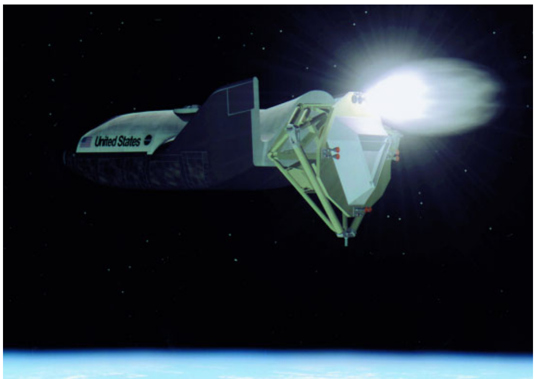
The scope of ESA's participation will go beyond the X-38 partnership with NASA, and will include additional subsystems or elements, such as the foldable fins, the fin-folding mechanisms, the trunnion retraction/extension mechanisms, the crew seats and the hot structure body flaps and nose TPS (provided for X-38 by DLR's TETRA programme).

Europe's industrial team will also evolve from the X-38 team, with MAN Technologie and Alenia Spazio sharing the role of prime contractor, and leading a team of 19 subcontractors in Austria, Belgium, France, Germany, Italy, The Netherlands, Spain, Sweden and Switzerland.

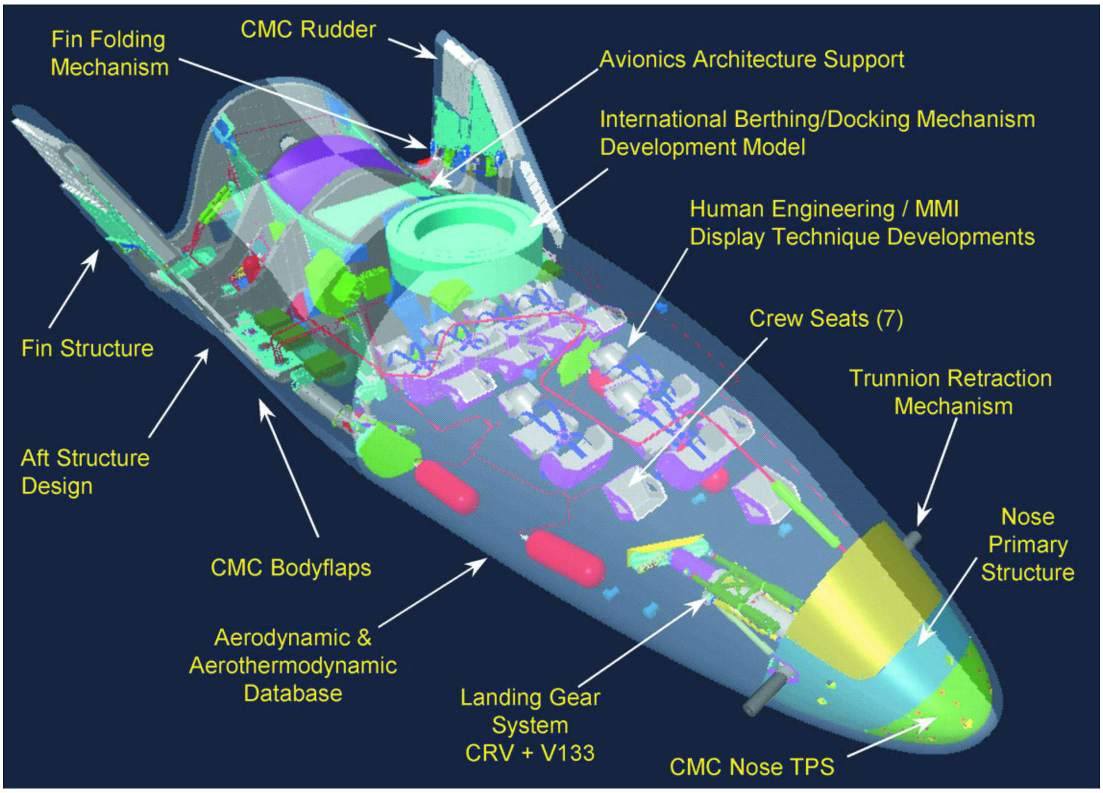


*The CRV can carry seven passengers. (NASA)*

ESA's CRV Programme is linked to the ISS Exploitation Programme: ESA is negotiating with NASA the terms of an Implementing Arrangement (Barter Agreement), under which ESA will receive NASA-provided Station services such as transportation and high data-rate services in return for ESA's CRV participation. CRV contributions will be deductible from the Station's variable costs under the exploitation programme.



*The Deorbit & Propulsion System fires to begin the descent. (NASA)*




*ESA's participation in the CRV programme.*


*X-38 V-131R is prepared for shipping from JSC. (NASA)*

## Genesis of the CRV Programme

The CRV is based on the X-38 technology demonstration and risk-mitigation pathfinder programme. ESA is developing 15 subsystems or elements of the V201 X-38 spacecraft, scheduled for launch by Space Shuttle Columbia in September 2002 (see *On Station*, December 1999; *ESA Bulletin*, February 2000). In addition, ESA is providing the GNC software for the parafoil phase of the V131R and V133 aerodynamic drop-test vehicles, and for the supporting tests using a parafoil microlight aircraft and large drop pallets flying the full parafoil.

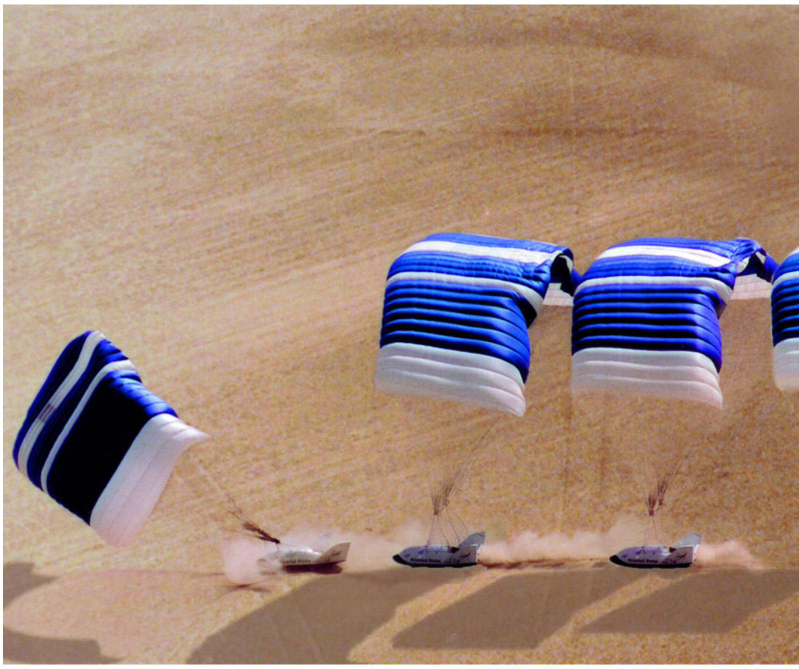
The X-38 family of prototypes is supporting a robust flight test programme, providing the flexibility to operate and evaluate multiple flights with parallel rapid turnaround of the test results.

The X-38 is an innovative combination of a lifting body shape (first tested as the X-24 in the late 1960s and early 1970s) and today's latest aerospace technology, including CMC hot structures for control surfaces and nose TPS, the world's largest parafoil, GPS in combination with an inertial platform for primary navigation, and laser-initiated pyros for deploying parachute and parafoil, deploying the Landing Gear System and removing the inhibits for trunnion retraction.

X-24 flight tests resolved technical issues critical to developing the Space Shuttle, the first reusable space transportation system. Today, the X-38 continues that tradition for the next manned spacecraft.

The growing depth of X-38 design data combined with continued flight testing is leading to the desired level of crew safety and reliability for the final CRV design. In addition, zero-gravity tests using NASA's KC-135 aircraft are helping to define CRV operational capabilities and man-rating aspects, including crew ingress and egress, seat design and display techniques.

In a rapid prototyping environment and using effective management and decision-making processes, ESA is developing X-38 subsystems at an unprecedented low cost. Flight-testing enabling technologies for man-rated, reusable reentry vehicles creates the base for European industry's significant role in CRV development.



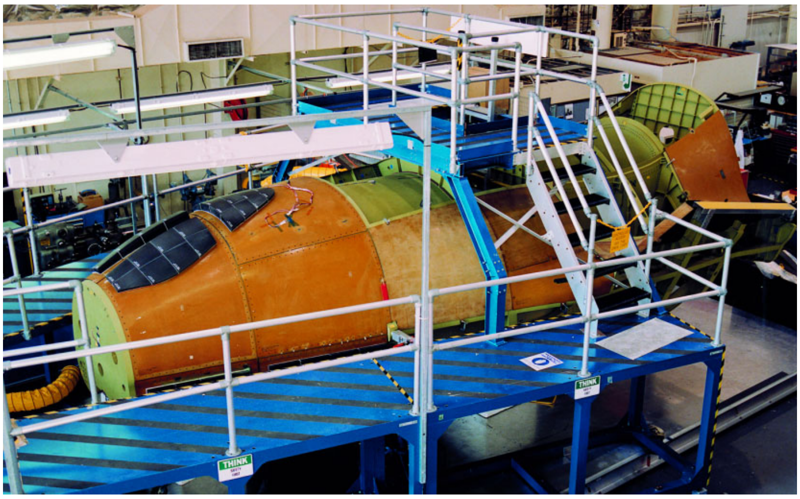

*The X-38 drop test vehicle V131R, at Dryden before its maiden flight.*

## X-38 Status

Most of ESA's subsystems have been delivered for system-level integration at JSC. Recent deliveries were the Pyrex sensor, the nose primary structure and the first batch of TPS blankets. The CMC leading edges and the fault-tolerant computers (derived from ESA's DMS-R;

## CRV and European Industry

| | |
|---|---|
| *Austria* | MAGNA: foldable fin |
| *Belgium* | SONACA/SABCA: aft structure, empennage |
| | SAS/Spacbel: software independent validation, displays & controls/Man-Machine Interface |
| | Verhaert: trunnion mechanism, IBDM |
| *France* | AML: aerodynamics |
| | Dassault: aerodynamics/aerothermodynamics |
| | ONERA: aerodynamics |
| *Germany* | Astrium: parafoil GNC, software independent validation |
| | DLR: CMC nose thermal protection, aerodynamics/aerothermodynamics |
| | MAN Technologie: industrial lead, body flap assembly |
| *Italy* | Aermacchi: aerodynamics |
| | Alenia Spazio: industrial lead, nose primary structure |
| | CIRA: aerothermodynamics, Scirocco plasma facility |
| | SICAMB: crew seats |
| *Netherlands* | Fokker: rudders |
| | NLR: aerodynamics |
| *Spain* | Sener: landing gear, IBDM |
| *Sweden* | FFA: aerodynamics |
| *Switzerland* | Contraves: fin folding mechanism |


*The X-38 spacecraft V201 in assembly at JSC. (NASA)*

The V201 spacecraft will be powered up in March at JSC, followed by the modal survey test in July and the acoustic test in September. Shipping to the Kennedy Space Center is scheduled for April 2002.


*First flight test of the X-38 vehicle V131R, in November 2000. (NASA)*

see the article in this issue) with adaptive reentry software will be accepted and shipped to JSC in the next few months. The Landing Gear System is ready for assembly once test fixtures are received from NASA.

The V131R, the latest aerodynamic vehicle, refurbished to reflect CRV's shape, was successfully flight-tested for the first time in November 2000; five more V131R flights are scheduled, beginning in May. November's test scored a number of firsts: first flight of the real (ESA-designed) vehicle shape; first flight of the full parafoil; first flight controlled by ESA's GNC for the parafoil phase.

### The Future

While the X-38 has been designed to address the specific needs of the CRV programme, it is a flexible, robust and cost-effective testbed that will answer a wide range of key questions about technologies and operations of future reusable manned spacecraft. It helps researchers to probe the hypersonic transatmospheric flight regime, and it addresses questions fundamental to industry's future capability for developing operational fully or partially reusable spacecraft.

There is a need to take a closer look at potential future developments beyond the CRV. A Crew Transfer Vehicle (CTV) may be the next logical step, eventually complementing the Space Shuttle. A potential evolutionary path from the X-38/CRV to a CTV could be an initially space-based, fully operational vehicle offering augmented on-orbit capabilities such as rendezvous and docking, as well as routine landing on runways. Evolutionary development from the CRV would be a cost-effective transition for ESA and European industry into the next generation of reusable manned spacecraft. A European CTV preparatory programme should be started in the near term to secure a key role for Europe in future human spaceflight and exploration.

# DMS-R in Control

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*The DMS-R data management system provided by ESA for the Zvezda module of the International Space Station has now been operating successfully in orbit for more than 6 months...*

### What is the Data Management System?

DMS-R provides command and control for Zvezda and the entire Russian Segment, guidance, navigation and control (GNC) for the whole Station, and mission management by ground control and crew. The project's history goes back to 1992 when discussions began with Russia on ESA contributions to a Mir successor. It was only in 1994 that the project took shape with the fusion of the Mir-2 and Freedom programmes into the International Space Station. ESA agreed to provide a set of highly advanced computers as the core of the avionics for the Russian Service Module. In parallel, ESA benefits by reusing these computers for its own Columbus and Automated Transfer Vehicle (ATV).

### DMS-R Design, Development and Delivery

The DMS-R architecture (see figure) consists of:

- two Fault Tolerant Computers (FTCs) serving as Zvezda's Central computer (CC) and Terminal Computer (TC) connected to MIL-STD 1553 busses. They have built-in fault masking and each consists of three interconnected identical processing units (lanes) working by majority voting;
- two Control Posts (CPs) for the crew and for commanding experiments and the European Robotic Arm via MIL-STD 1553 busses. They can be configured to execute different tasks or to operate redundantly. Each CP can use two laptops (commercial ruggedised PCs, standardised, qualified and provided to all Station partners by NASA) as the Man-Machine Interface;
- the ground infrastructure and facilities for software development, integration and test.

Development started in 1994 by a European consortium headed by DASA in Bremen (D), leading to delivery of the first flight units to Russia's Zvezda contractor RSC Energia in November 1997. The software underwent refinement from 1998 to early 2000, based on field experience and implemention of late changes in hardware and software requested by RSC Energia as they developed Zvezda's application software.

### Flight Experience

An ESA/Industry support team worked jointly with Russian flight controllers at the TsUP control centre near Moscow during launch, docking with Zarya and installation of the first Control Post computer and laptops by the Expedition-1 crew.

On 12 July 2000, the two FTCs were activated 2 hours before launch from Baikonur. Telemetry was monitored, especially the internal temperature. Telemetry was limited during Proton ascent but what was available was normal. When Zvezda separated from Proton, commands were triggered in the two computers to deploy the module's external elements and to switch onboard systems from stand-by into active mode. Before Zvezda passed out of ground station contact, all performances were verified as normal. The other orbital passes during this first day saw various equipment commands and activation inside Zvezda from TsUP, with constant monitoring on the consoles. Some 3 hours after launch, temperatures inside the computers had stabilised at 35ºC, well below the prediction used during development to assess their reliability. It is therefore expected that each

*Gidzenko working with the laptops of the Control Post computers.*

computer will exceed its calculated life of up to 5 years.

The next 2 days saw the main engines adjust the orbit under DMS-R control, as well as various GNC testing and verification using star sensors and inertial navigation systems. Flight controllers performed an end-to-end test of the radio command and telemetry system with the DMS-R computers, ensuring proper command and telemetry configurations while cycling through Zvezda's various software modes.

On one occasion, a general exception in the application software of the Terminal Computer led to a reset. The computer successfully restarted and returned to normal operation without losing attitude control. Discussion between RSC Energia and DMS-R support engineers produced the explanation that a ground command to the SIMVOL display system provided an unexpected erroneous response. Mass restrictions had forced Zvezda to be launched with only a subset of SIMVOL for rendezvous and docking.

The day before docking, controllers noted that a CC lane was in standby mode. Initial analysis concluded there was no error in the DMS-R hardware or software and that the anomaly resulted from the application software response to some specific timing conditions. It was recommended that docking could proceed as normal with the 2-lane CC.

The docking was successful in this configuration. However, during the first orbit after docking, telemetry indicated that another CC lane had also reset and was in standby, leaving only one active lane. After a data dump via the telemetry system, it was assessed that the cause was the same. Meanwhile, the CC continued to perform normally. However, ESA and RSC Energia engineers agreed that reestablishing the three lanes was necessary before DMS-R was connected to the Station bus. The integration of Zvezda's CC data busses with the computer systems of Zarya and Unity then proceeded without problems. DMS-R's computers were now not only responsible for Zvezda command and control but also for GNC for the whole Station.

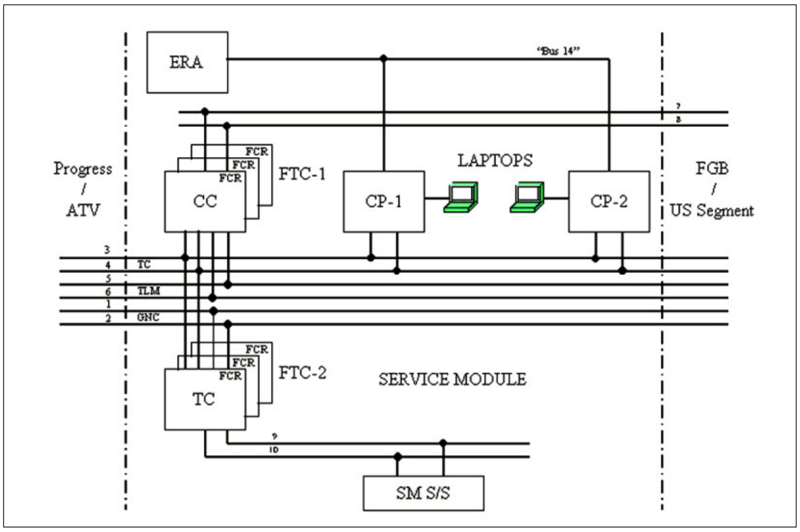
The two computers continue to perform normally despite a few more instances of lane isolation. They are not critical and RSC Energia engineers devised a fix for the application software to be uploaded before the arrival of the US Destiny laboratory in February 2001.

One CP computer and its two laptops arrived aboard the Progress-M1-3 supply ferry in August 2000. They were unloaded by the crew of STS-106 in September and on 4 November the computer and laptops were mechanically installed, cabled, switched on and booted by the Expedition-1 crew. The full activity took 3 hours, spread over three orbits because of incomplete ground coverage. With this installation, the crew could now command Zvezda.

However, in mid-November, one laptop would not reboot and when the second suffered the same problem 2 weeks later the crew could no longer interact normally with Zvezda. As of January 2001, the problem was still under investigation and not fully understood. It is not a hardware failure, but more probably a corruption of the SOLARIS operating system on the laptop hard disk after a non-nominal shutdown or crash. Without a backup, the crew could not recover the situation. STS-97 delivered a new hard disk in December with configured software so that the crew could recover one laptop. The faulty hard disk was brought back by the Shuttle for analysis.

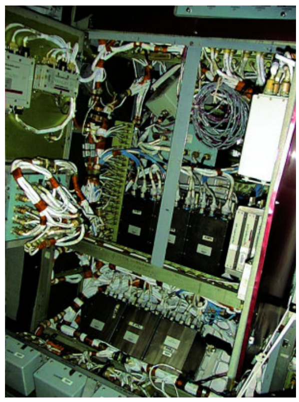
## The Future

The second CP computer was delivered by STS-98 in February and installed by Expedition-1 that month, completing the full on-orbit configuration of DMS-R. In order to provide long-term support, identical new Fault Tolerant Computers are being manufactured by Astrium to be available from March 2001 for use as required. Some of the computers will be provided under the original DMS-R agreement, while others are in exchange for Russian support for ATV. ESA is also negotiating with Russia to provide long-term DMS-R engineering support throughout the life of the Station.




*DMS-R architecture aboard Zvezda. CC: Central Computer. TC: Terminal Computer. FCR: Fault Containment Region. FTC: Fault Tolerant Computer. CP: Control Post. SM S/S: Service Module subsystems. FGB: Zarya module. ERA: European Robotic Arm. ATV: Automated Transfer Vehicle. TC: telecommand. TLM: telemetry. GNC: Guidance, Navigation & Control.*

*The two sets of 3-box Fault Tolerant Computers of DMS-R installed in Zvezda before launch.*



# Transmitting from Space

## The Global Transmission Services Experiment

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### Introduction

In 1996, following the successful Euromir-95 mission, ESA negotiated with RSC-Energia the Euromir Extension mission. Euromir-E should have taken place towards the end of 1997, and reused much of ESA's equipment already onboard Mir. However, the Progress collision in June 1997 destroyed these plans – the vast majority of ESA's equipment became inaccessible inside the damaged Spektr module.

*The Global Transmission Services project will be Western Europe's first major experiment aboard the Space Station....*

Instead, ESA and RSC-Energia agreed at the end of 1997 to devote the financial resources from Euromir-E to Western Europe's first scientific endeavour on the International Space Station (ISS). At this stage, GTS was an experiment proposed by the German Steinbeis Transferzentrum Raumfahrtsysteme (TZR) and was highly recommended by the ESA Peer Groups. Following an in-house feasibility assessment, GTS stepped in to replace Euromir-E.

*The GTS Antenna Unit installed on Zvezda.*

### The Objectives and Concept of GTS

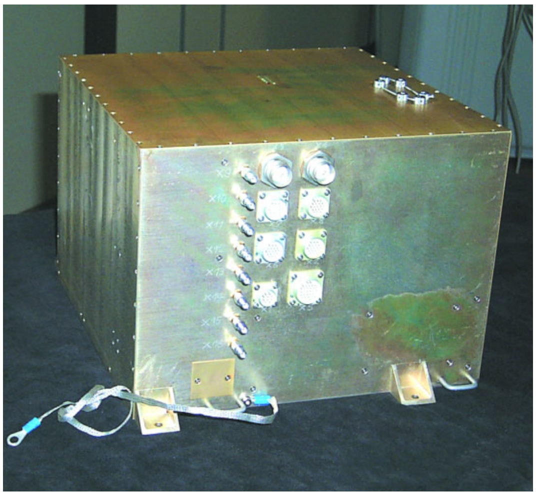
Time-signal stations on Earth usually transmit their information at long wavelengths. Watches synchronise themselves with these signals by activating their receivers typically once per day or after turn-on. In Germany, the signal is broadcast by the Physikalisch-Technische Bundesanstalt (PTB), in Braunschweig, using a simple encoding scheme to transfer both time information and synchronisation impulses on a 77 kHz carrier. Although this scheme is quite efficient and simple, it has several disadvantages:

- the time signal is only Europe-wide, within 2000 km;
- moving between countries requires different receivers and decoders;
- the low data rate requires lengthy, good receiving conditions.

To overcome these limitations, GTS will transmit a UTC time signal from the Space Station via an external antenna with a broad antenna pattern. The Station's orbit means that this signal is transmitted over almost the whole Earth each day. The signal can be received at any location several times daily, for 5-12 minutes at a time, strong enough for even small wristwatches. GTS also broadcasts the Station's current orbital position, so clocks 'know' their local time zone without user interaction.

Further main scientific objectives are:

- to verify the performance and accuracy of a time signal transmitted to the Earth's surface from low orbit under real space operational conditions;
- to measure the signal quality and data rates on the ground;
- to measure disturbing effects such as



*The flight model of the GTS Electronics Unit.*

Doppler shifts, multi-path reflections, shadowing and elevation effects.

## Experiment Set-up

GTS essentially consists of two major elements in the Station's Russian Zvezda module: the Electronics Unit (EU) and the Antenna Unit (AU).

The EU accommodates all the elements for the experiment, signal generation and signal distribution. In addition, it provides the necessary command and control interfaces with the Station's Russian Segment for GTS data exchange, telemetry transfer, GTS telecommanding and data receipt from Zvezda's systems, such as orbital data.

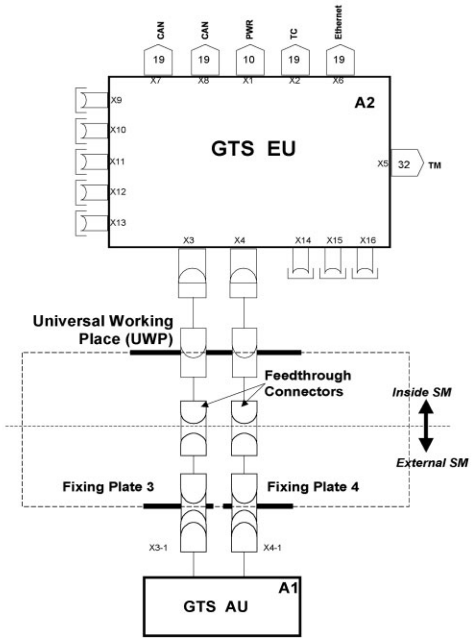
A main EU feature is the ultra-stable quartz oscillator (USO). This oscillator is the core of the local time generator, and provides an accuracy of up to $10^{-13}$. If synchronised almost every orbit with an atomic clock on the ground – such as the one at PTB – GTS generates an onboard time-signal reference of unprecedented accuracy for the Station's own applications. GTS provides this signal to Zvezda's systems and other scientific onboard users via a pulse and frequency output.

Being only 350x300x210 mm in size, the EU will be housed in the Zvezda module, behind Panel 408.

The EU generates the GTS signal on two frequencies – 400.1 MHz and 1.4 GHz – for transmission to Earth by the AU. The transmitter includes a digitally controlled frequency synthesiser that allows testing of various frequencies and modulation techniques. Specific modulation techniques will be applied in order to avoid interference with other ground-to-space links aboard the Station.

The antenna has specially shaped radiators to create a near-constant signal strength on the ground down to 15° above the horizon for the receiver during the Station's pass. The UHF main beam uses a 4-element phased array. The beam can be rotated in eight steps with an angle of 70° relative to nadir using beam-forming electronics located on the back of the antenna plate. The power and command signals are routed together with the RF signals through two coaxial cables. For extended services, requiring larger bandwidths than a time signal, the L-Band (1.4 GHz) with its dedicated antenna on the AU is used.

In December 1998, the AU's hardware development, integration and test activities ended with its installation on an EVA handrail on Zvezda, along with the RF cables. Zvezda and the AU were safely launched into orbit in July 2000.




*GTS block schematic.*

## Experiment Operation Summary

Data and time information destined for GTS will be transmitted from the experimenter's site in Stuttgart, Germany and directly received by GTS. The ground station will supply GTS with the synchronisation marks and pre-calculated ground track information needed to minimise the active time for the ground receivers. The GTS internal clock is adjusted and/or synchronised using this dedicated uplink. In order to maintain this clock's very high accuracy, this adjustment is required at least once per day.

The Mission Control Centre in Moscow

(MCC-M) will control the on/off of the GTS Electronics Unit. In addition, a dedicated capability controlled by MCC-M allows individual transmitter switching in specific operational cases.

The GTS continuously transmits time and and information on the Station's position along its ground track. These data are complemented by GTS housekeeping telemetry. Equipment status and housekeeping data will also be transmitted via a dedicated telemetry interface to MCC-M. The GTS time signal can be issued via the dedicated data interfaces to the Station's data management system to serve as the reference time signal for the whole Station.

In order to maximise the scientific return GTS will operate autonomously and preferably continuously. Intervention, such as the switching of transmitters, is normally performed by MCC-M and not the crew.

Interrupting the experiment runs (power shut-off, transmitter switching) needs to be avoided. Reactivation after any shutdown of the experiment costs 8-10 days in clock recalibration before the measurements can run normally. GTS is designed to operate continuously for the 2 years agreed with RSC-Energia.

### Status and Planning

The GTS Electronics Unit completed Final Flight Acceptance in mid-March, aiming for launch to the Station aboard a Progress ferry towards the end of April. It is envisaged that the Expedition-3 crew will install the EU and activate GTS around the beginning of July 2001. Then, after functional verification, GTS can be declared operational towards the end of that month.

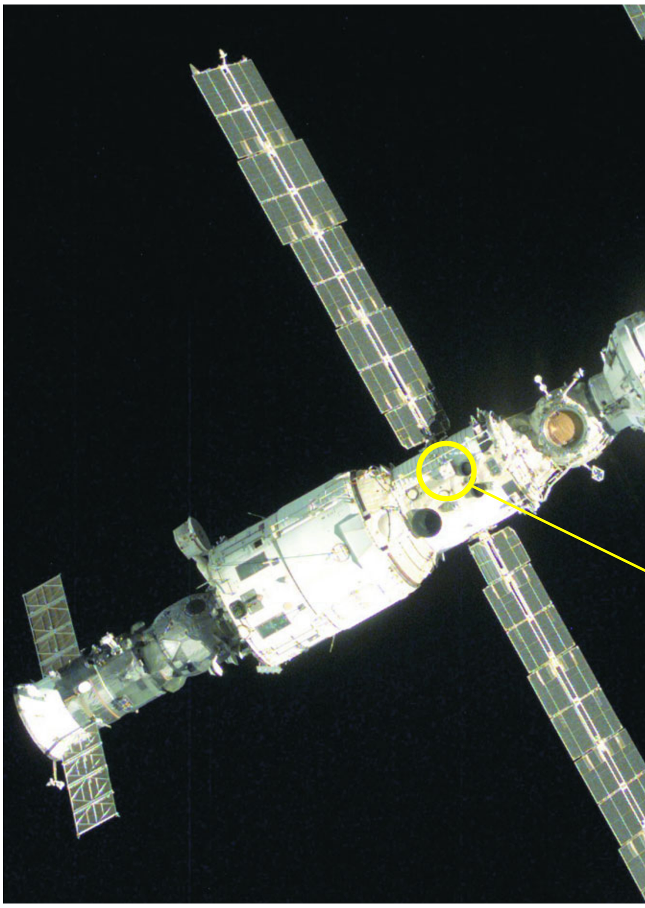
### GTS Applications

At present, two concrete applications are foreseen:

- time signals for worldwide clock synchronisation,
- secure code transmission for anti-theft devices that can deactivate a stolen car and its keys.

It could be argued that the clock application could also be implemented using Global Positioning System signals. However, GPS has major drawbacks:

- no local time zone information (political and/or geographical) is provided;

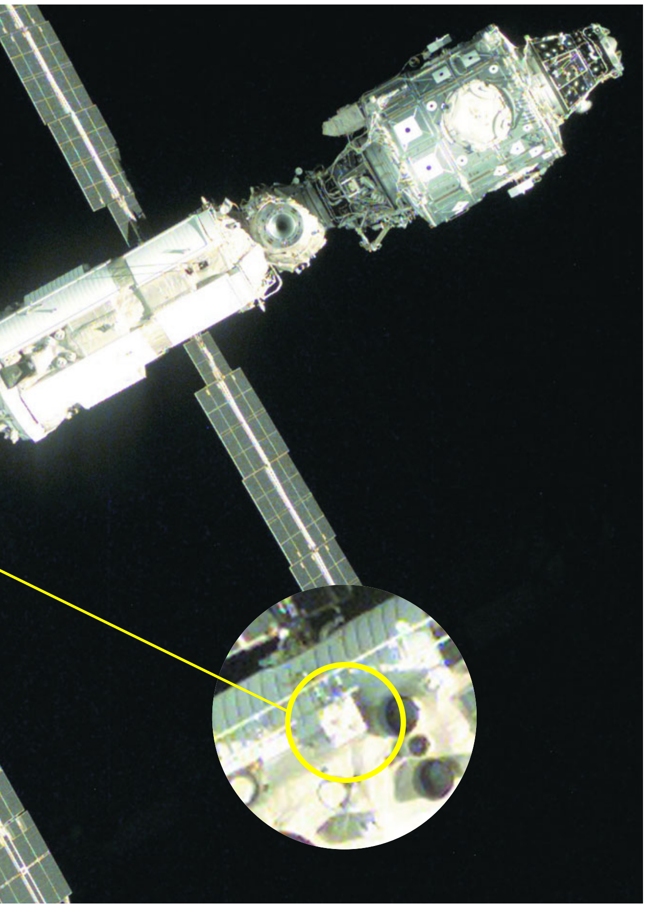


- no daylight savings time information is generated;
- without L-band signals, wristwatches cannot use the service;
- GPS is a military system and can deliberately broadcast erroneous signals if required.

In order to minimise the computational effort and power consumption in wristwatches, GTS continuously transmits the local time for the Station's current ground spot. The receivers detect the moment of the closest Station approach by measuring the signal's Doppler shift. The ambiguity of a left or right passage is resolved using the rotating beam information. From these data, the receiving clock determines the correct time data packet for its current position. Via the EU's computer, changes in time zones, daylight savings and UTC time adjustments can be easily implemented through commands from the controlling ground station.

Compared with GPS, the Station is an ideal platform for instant repairs and, in comparison with satellites, offers rapid replacement of faulty hardware via the frequent upload opportunities and crew availability. This approach offers simpler design solutions, which lower development cost and save time.

The anti-theft application demands a secure signal to receivers small enough to be



*The GTS Antenna Unit on the Zvezda module.*

integrated into car keys. Such a signal must be:
– difficult to imitate, so that it cannot be faked with a transmitter on the ground;
– non-repeating, so that it cannot be recorded and replayed to simulate a true signal;
– fail-safe, i.e. the hardware must be redundant and easy to service.

The combination of non-linear pseudo noise spectrum signals, the large Doppler shift and the orbit information form a fingerprint that cannot be faked by car crackers on the ground.

### The Commercial Potential of GTS

From the beginning, GTS was conceived as a commercial application. It has followed not only a new approach to developing space hardware for new services, but also an approach on how future operations costs can be financed through a 'service provider company', founded by the development and research partners and financed through selling licences and specific services to end users.

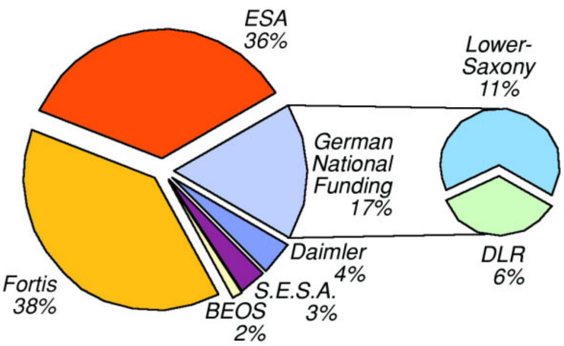
The commercial structure of the GTS Development Project can be summarised as:
– the main industrial partner in the ground segment is Fortis Uhren GmbH, who developed the hardware for the experiment on their own and who will make the required ground tests using the Station signals, thereby implementing the standard GTS services that are the core of the commercial utilisation;
– TZR developed the space segment (supported by DLR) and is coordinating the scientific utilisation of GTS;
– the flight opportunity, covering integration and launch, the operation in space during the 2-year experimental phase, and associated ground infrastructure services (e.g. data exchange with MCC-M) is provided by ESA.

GTS aims at near-term commercialisation and is therefore financed by industry to a significant extent. The ground segment required the development of new receiver chips and their integration into wristwatches and car electronics. The total development budget is about EUR6.5 million, of which 53% is public funding (ESA and German national) and 47% is industrial funding.

During the 2-year initial experiment phase, the GTS hardware will be operated by TZR, the scientific coordinator. Plans are already taking shape to found a GTS Service Company, with the partners participating as 'shareholders'. Commercial utilisation during this initial phase will then be coordinated through the Service Company. As ESA is providing the flight opportunity and operations, as well stimulating Station commercialisation, it will participate in the company.

For the future, apart from managing GTS licensing and providing continued services, the Service Company will most likely also have to establish contracts with the Station Partners in order to ensure continued GTS services on the ISS, make hardware upgrades and issue and manage licences to end-users to refinance the operational costs of the hardware or invest in future developments.

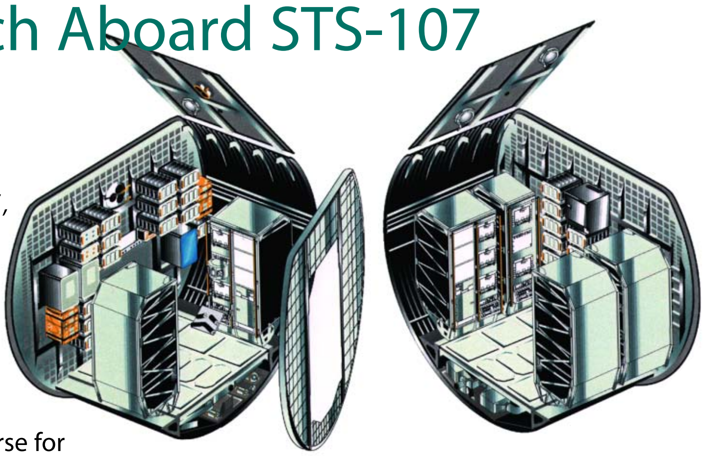
The main GTS ground station will be operated by the Service Company. It will also take responsibility for user interfacing, data processing, transmission to and from the GTS hardware (e.g. in the case of car theft protection activation) and provide marketing and promotion services. ■




*GTS development costs share.*

# Bridging the Gap

## ESA's Microgravity Research Aboard STS-107



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### Introduction

For 15 years, Spacelab was the workhorse for western research in the life and physical sciences under microgravity conditions ($10^{-5}$-$10^{-6}$ *g*), stretching from the first mission in 1983 to its last, Neurolab, in 1998. The international microgravity user community recognised early on that the International Space Station (ISS) would not be fully operational for its needs before 2005. It thus urged NASA to bridge the long gap in research opportunities by flying microgravity payloads on Shuttle missions.

*Shuttle mission STS-107 will be a major flight for ESA's microgravity research programme...*

The first, STS-95 in late 1998, included an ESA microgravity package with the Advanced Gradient Heating Facility (AGHF), Advanced Protein Crystallisation Facility (APCF), Biobox, Facility for Adsorption and Surface Tension (FAST) studies and Morphological Transitions in a Model Substance (MOMO) facility. STS-95 is perhaps better known as the John Glenn and Pedro Duque flight! After this mission, NASA agreed to include a series of research missions in the Shuttle manifest. These will use Shuttle *Columbia*, which is too heavy for ISS assembly or supply flights, but it has an extended duration operations kit for missions of typically 16 days. The commercial Spacehab pressurised module carries the research equipment.

**STS-107**

*Launch:* October 2001 (depends on higher-priority ISS and Hubble Space Telescope missions)
*ESA payload:* APCF, ARMS, Biobox, Biopack, ERISTO, FAST, COM2PLEX
*Payload mass:* 3630 kg (3300 kg in Spacehab & 330 kg in middeck), including 580 kg from ESA
*Mission duration:* 16 days (+2 days margin)
*Orbit:* altitude 280 km, inclination 39º
*Crew:* 7, working in two shifts

### The STS-107 Mission

The Spacehab Research Double Module (RDM) will make its maiden flight on STS-107. NASA's rental agreement makes owner Spacehab Inc. and subcontractor Boeing fully responsible for payload integration in the RDM and in the Shuttle middeck, and for its operation during flight, controlled from NASA's Johnson Space Center (JSC) in Houston, Texas.

Payload integration, verification and test is underway in the Spacehab Payload Processing Facility (SPPF) in Port Canaveral, Florida, next to the Kennedy Space Center (KSC) launch site.

### The ESA Payload

Spacehab missions are organised commercially, which means that access has to be contracted with Spacehab, Inc., normally on a US$/kg price basis. For STS-107, this applies to 230 kg of ESA's payload. But there are other ways to get aboard:

- 300 kg come from the barter arrangement with NASA in return for providing a Guppy transport aircraft;
- 50 kg are an ESA ergometer counted as NASA return for including a US experiment in Biopack.

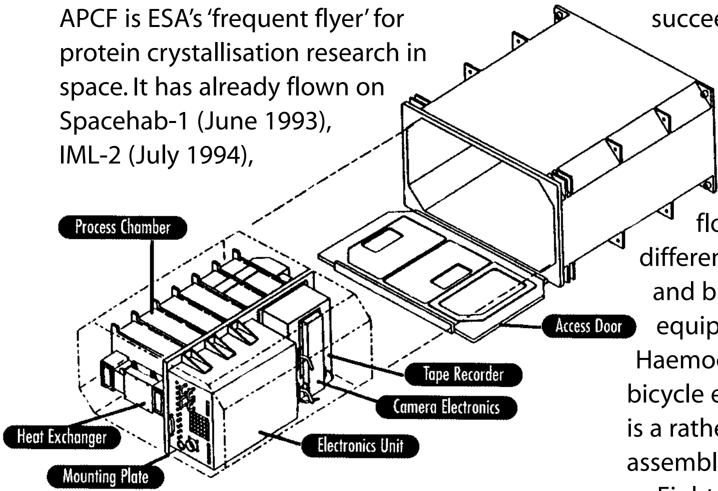
ESA's payload encompasses seven separate facilities. Apart from the COM2PLEX technology facility of the Technology Flight Opportunities (TFO) Programme, they are all funded by the European Microgravity Research Programme (EMIR). In total, 37 ESA life and physical sciences experiments will be accommodated on STS-107.

The experiment 'Choroidal regulations involved in the cerebral fluid response to altered gravity: water transports and serotoninergic receptors' requires rats to be housed in NASA's Animal Enclosure Module (AEM). As this is similar to a NASA experiment, ESA's researcher will receive her rat tissues from NASA within a day of landing.

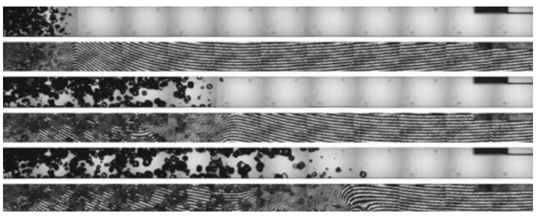
## Advanced Protein Crystallisation Facility

APCF is ESA's 'frequent flyer' for protein crystallisation research in space. It has already flown on Spacehab-1 (June 1993), IML-2 (July 1994), USML-2 (October 1995), LMS (June 1996) and STS-95/Spacehab (October 1998). ESA has two identical flight models that can each carry up to 48 individual and different experiment growth reactors, of which up to 12 can be observed by a video and a Mach Zender Interferometer subsystem. Protein growth temperatures can be selected between 4°C and 30°C (20°C for STS-107). APCF requires an astronaut to turn it on and off but it otherwise automatically follows a preprogrammed processing profile that includes the recording of up to 5000 video/interferometer stills.

APCF is designed for Shuttle Middeck Lockers (MDLs), which means it can fly on the actual middeck, Spacelab, Spacehab, ISS Express and ISS European Drawer Racks. MDLs allow late access before launch and soon after landing – a prerequisite for sensitive proteins, since some degrade rapidly after insertion into their growth reactors. On STS-107, eight experiments occupy 38 growth reactors.




*APCF design and accommodation in an MDL.*



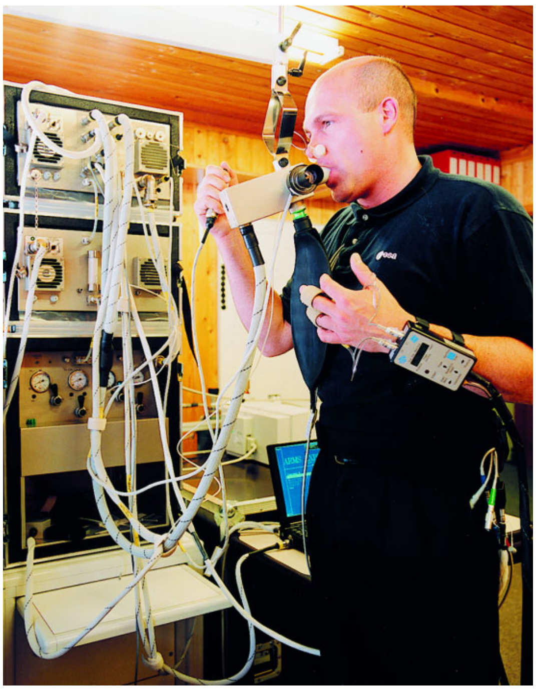
*Protein crystals grown in APCF during STS-95. Interferometry shows the evolution of salt and protein concentration in the reactor chamber. (J.M. Garcia Ruiz et al.)*

The second APCF flight model will probably fly even earlier than STS-107: it is being prepared as ESA's first microgravity payload aboard the Space Station. It will be launched with ISS assembly flight 7.A1 in mid-2001 to be installed in an Express Rack in the US Destiny Lab, and returned on UF-1 in November 2001.

## Advanced Respiratory Monitoring System

ARMS is a new development, mainly for pulmonary and cardiovascular research, succeeding instruments flown as part of Euromir and Anthrorack aboard Spacelab-D2. ARMS' core instruments are two Photo- and Magnetoacoustic Gas Analysers complemented by instrumentation such as valves, flowmeters, gas supplies with four different gas mixtures, blood pressure, ECG and breathing frequency measurement equipment, Infrared Pulse Oxymeter, Haemoglobin Photometer Spirovis and a bicycle ergometer to stress the subjects. ARMS is a rather complex set-up that astronauts assemble in orbit from many stowed items.

Eight groups of investigators will use ARMS during STS-107, although one will make measurements on the whole crew only before launch and after landing. The research fields cover heart control and regulation, pulmonary physiology (including both lung mechanics and gas exchanges) and orthostatic intolerance. The experiments will be performed at the mission's beginning, mid-point and end



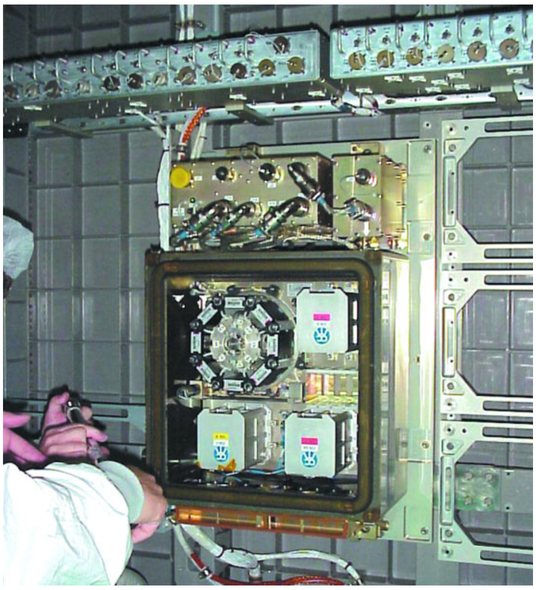
*ESA astronaut Andre Kuipers tries the ARMS Training Model.*

*Biopack: the top compartment carries the refrigerator/freezer; the incubator and centrifuges are in the bottom.*

to study both the early adaptation and the achieved steady-state. This requires a total crew time of about 78 hours.

In addition, an important part of the research is done on the ground: pre-flight to establish the individual reference baseline of each of the four ARMS astronauts, and post-flight to study the return to 1 *g*. Both fast- and slow-recovery systems will be studied after return (landing +2 hours) until a month and a half later.

Training is an important part of the mission preparation. The crew has to learn to set-up, stow and use the equipment, and to perform the different breathing 'manoeuvres', such as controlling inspiration or expiration flow at 0.5 litre/s.



*Biobox, with the lid removed, is installed in Spacehab.*

### Biobox

The multi-user Biobox was originally designed to fly on Russia's Foton and Bion retrievable capsules. After three flights in 1993, 1995 and 1997, it was adapted for Spacehab and made its first flight on STS-95.

Biobox is essentially an incubator (6-38°C) that can accommodate 24 experiments in static (microgravity) positions and six in a 1 *g* reference centrifuge. Biobox works 'hands-off' – it runs automatically from installation in Spacehab until landing. The temperature and centrifuge speed can be adjusted by ground control by telecommand.

During STS-107, four experiments will use bone cell cultures (osteoblasts, haemopoietic cells and osteoclasts) from humans and mice. A second Biobox will operate on the ground as a 1 *g* reference.

### Biopack

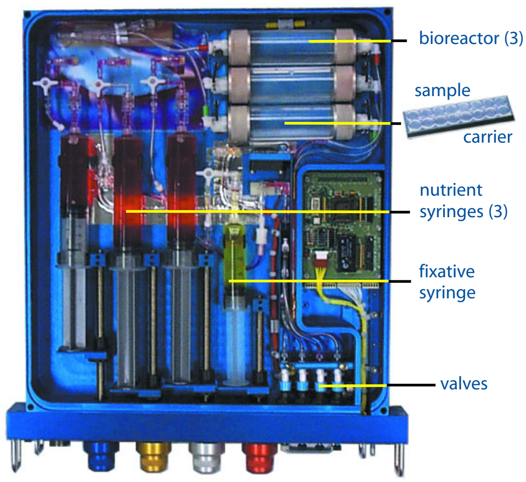
Biopack is now finishing development for its debut on STS-107. It is designed to fit in any double-MDL position in the Shuttle, Spacehab, ISS Express Rack or ISS European Drawer Rack. Biopack is an incubator (22-37°C) with static (microgravity) and dynamic (three centrifuges controllable 0-2 *g*) accommodation positions for standard experiment containers of Type 1/E (65 ml internal volume) and Type 2/E (385 ml). For storing experiment containers, Biopack includes a refrigerator/freezer (4°C or -15°C) and a freezer (-15°C).

Apart from astronauts handling experiment containers, Biopack can be run fully automatically with telescience control from the ground. However, all functions can also be monitored and controlled from its Control and Monitoring Panel by the astronauts. On STS-107, Biopack will be used for eight experiments in 78 containers on mammalian cell and tissue cultures, and bacteria.

As for other biology facilities, the Biopack engineering model will run on the ground during the mission as a 1 *g* reference.

### European Research in Space and Terrestrial Osteoporosis (ERISTO)

ERISTO, one of more than 40 ESA Microgravity Application Projects (MAP), makes use of the OSTEO facility developed and already flown by the Canadian Space Agency on STS-95.




*An ERISTO payload tray.*

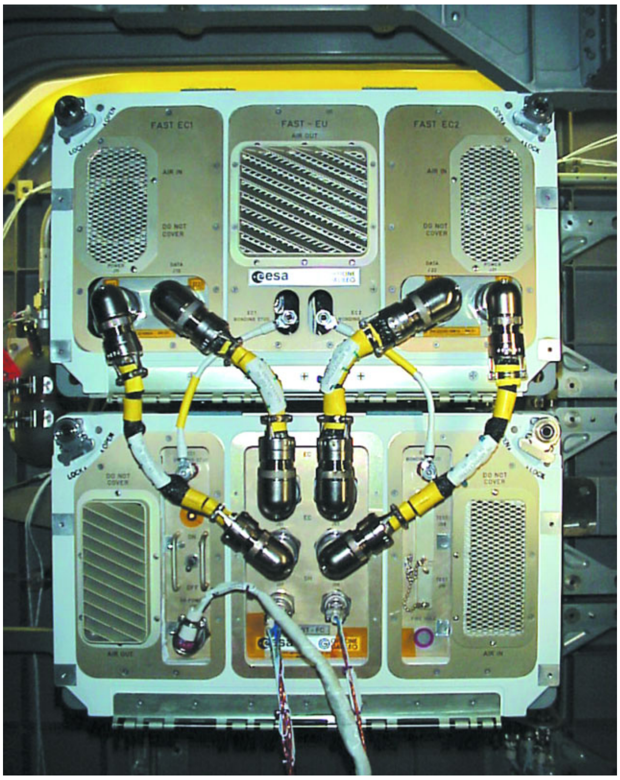
ERISTO's long-term goals are a better understanding of the role played by mechanical stress in osteoporosis and to help develop countermeasures against bone-loss on long space missions. It is hoped that the results can be adapted to fight osteoporosis on Earth.

Two ERISTO experiments will study the responses of osteoblasts (bone-forming cells) and osteoclasts (bone-resorbing cells or cells that break down bone) to various drugs and growth factors under microgravity conditions (i.e. under reduced mechanical stress).

ERISTO consists of an incubator housing four identical trays with three experiment specimens each. The Spacehab locker will be installed only 40 hours before launch. In orbit, the crew will follow a precise procedure in operating valves, syringes with nutrients and syringes with fixatives. The same will be done with the 1 *g* reference ERISTO unit on the ground.

### Facility for Adsorption and Surface Tension

Following its debut on STS-95, FAST will run a series of experiments to measure the response of surface tension to carefully controlled dynamic changes in surface area, free from the perturbing effects of buoyancy and convection that limit ground-based investigations. While executing its three experiment programmes semi-autonomously, FAST will send science and housekeeping data to the ground by video and telemetry. Telescience will allow the investigators to modify experiment parameters and experiment sequencing by telecommands, if required, after a preliminary analysis of the science results.




*FAST installed in Spacehab for Interface Verification and Testing.*

FAST is carried in two adjacent lockers on Spacehab's aft bulkhead: one for the Facility Controller and the other for the two Experiment Units. The Principal Investigators are involved in ESA's MAP on Fundamental and Applied Studies of Emulsion Stability that foresees FAST flying aboard Columbus.

### COM2PLEX

The COMbined European 2Phase Loop EXperiment has integrated three different loop heatpipes into one technology experiment, mounted outside on Spacehab's flat roof. Loop heatpipes – highly efficient heat transport systems using an evaporation/condensation cycle inside a closed loop (similar to classical heatpipes) – have been developed in the last few years and are key technology elements for deployable radiators, thermal control of laser-based instruments, and heat transfer from remote equipment to radiators. Two-phase phenomena (evaporation, condensation, two-phase flow) behave differently in 1 *g* and low-*g*, so testing and in-orbit qualification are mandatory to mature this new technology.

### Outlook

The only major uncertainty with STS-107 is its launch date, which could be between September 2001 and April 2002. This is because NASA awards higher priorities to Shuttle flights for the Space Station and Hubble Space Telescope than to microgravity research missions.

Another microgravity research mission is already being planned: STS-118 is assigned in the manifest. As our two agencies plan to refly part of STS-107's payload, a minimum gap of 15-18 months is required for refurbishing the experiment facilities. This means that STS-118/Spacehab is not expected to fly before spring 2003.

An unmanned microgravity mission is also in preparation: the 14-16 day Foton-M1 flight in late 2002. Negotiations with Rosaviakosmos are almost completed. ■

# Station Update

## Mission Accomplished!


The first phase of the long-term occupation of the International Space Station has been successfully completed. The Expedition-1 crew of ISS Commander Bill Shepherd, Soyuz Commander Yuri Gidzenko and Flight Engineer Sergei Krikalev returned to Earth on 21 March (as this issue went to print), having handed over to the Expedition-2 crew of ISS Commander Yury Usachev and Flight Engineers Jim Voss and Susan Helms.

During their 4-month tenure, the first crew hosted three visiting Shuttle teams delivering the first large solar arrays, the US Destiny science laboratory, Destiny's first science racks and the first Italian-built Multi-Purpose Logistics Module (MPLM).

STS-102/5A.1 docked with PMA-2 at 06:38 UT on 10 March to begin the second expedition. Usachev was the first through when the hatches were opened at 08:51 UT, immediately swapping places with Gidzenko. On 12 March, Voss took over from Krikalev, and Shepherd with Helms on 14 March. Shepherd remained in command until an hour before final hatch closing. As they switched, they exchanged their personalised seat liners in the Soyuz escape craft. The mission also continued the outfitting of Destiny through two spacewalks and the delivery of logistical items, spare parts and hardware in MPLM Leonardo. These included the first science racks, including the Human Research Facility, a mainstay for studying the effects of weightlessness on humans.


Usachev, Voss and Helms are expected to stay aboard until July, when they will be replaced by the Expedition-3 team of ISS Commander Frank Culbertson, Soyuz Commander Vladimir Dezhurov and Flight Engineer Mikhail Turin. During their tenure, they will host three Shuttle visits and begin research aboard the Destiny, outfitted by three MPLMs. Their Soyuz escape craft will be replaced by a fresh vehicle, and the Russians will add a docking compartment to Zvezda.

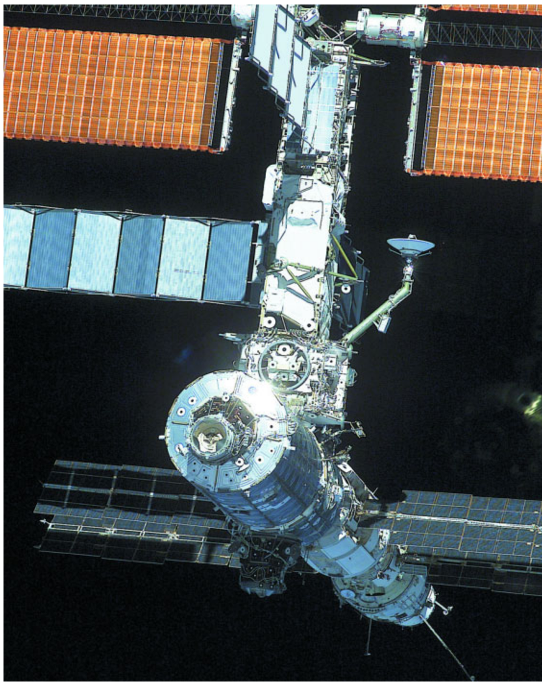
Umberto Guidoni will be the first ESA astronaut aboard the ISS as part of the Shuttle STS-100/6A mission in April. Late April will also see a Progress supply vehicle carrying the electronic unit for the European Global Transmission Services (GTS) experiment. GTS will allow the synchronisation of radio-controlled clocks and watches from space and, in the longer term, the disabling of stolen cars and credit cards. See the article on pp.10-13 of this issue for further information.

*On Station #4* (December 2000) took the story of Expedition-1 through the early days of their occupation. Their first Progress supply ship (#M1-4) brought 2 t of food, clothing, hardware and gifts from their families on 18 November 2000. Progress should have used the Kurs system to dock automatically with Zarya's nadir port, but failed to lock on. Instead, Gidzenko assumed manual control at 03:02 UT using the TORU system installed in Zvezda and guided Progress in using Soyuz-type hand controllers, but had to halt 5 m out when sunlight blinded the fogged camera lens on Progress. He moved the ferry back to 30-40 m and waited for orbital darkness before docking it at 03:48 UT. Soon after, the crew began leak checks at the docking interface before opening the hatches and beginning 7 days of unloading. This is the first time a radial docking port has been used on the Station. Progress was undocked at 16:20 UT on 1 December to clear the way for Shuttle STS-97's docking with the

# Station Update

*How the Space Station looked after the arrival of Destiny (bottom). The Soyuz escape craft (top) was later moved to Zarya. Inset: Cockrell (left) and Krikalev begin outfitting Destiny.*

*The Station's research activities will begin in earnest in Destiny (foreground) once the laboratory is outfitted. Shuttles will now dock at the axial PMA-2 position; PMA-2 is at Unity's nadir port.*



Unity/PMA-3 nadir position, again used for the first time.

STS-97 with Commander Brent Jett, Pilot Mike Bloomfield and Mission Specialists Joe Tanner, Canada's Marc Garneau and Carlos Noriega docked at 20:00 UT on 2 December 2000. Just over 2 hours later, Garneau used *Endeavour's* robot arm to lift the 16 t P6 solar array truss out of the cargo bay, leaving it positioned overnight to warm its components. The next day, Garneau slotted P6 into position at 19:32 UT on the Z1 truss structure on Unity. Spacewalkers Tanner and Noriega bolted it down before Garneau released it. Standing on the arm, Noriega moved around P6 to connect nine power, command and data cables. Computer commands from the Shuttle to release the pins holding the solar array containers closed were not initially successful. Repeat commands deployed the starboard wing in a 13-minute sequence but one pin on the port side remained closed. A radiator was then deployed to dissipate heat generated by the power module. The port wing was finally deployed on 4 December over a period of 2 hours. It had been delayed while ground controllers studied an apparent slackness in one of the two starboard blankets. They believed that two tensioning cables had jumped off their guides during deployment.

This first of the Station's four solar arrays, spanning 73 m, can generate 64 kW under optimum conditions from its 66,000 8 cm-sq solar cells. A second EVA by Noriega and Tanner, on 5 December, hooked up power and data cables and connected ammonia coolant lines between P6 and Unity. They also moved the S-band antenna assembly from Z1 to the top of P6's tower and released restraints holding another radiator, allowing it to be deployed after their EVA for early Station cooling. At the same time, the Station crew reconfigured cables inside Unity to route electricity from the new array to the rest of the Station. On 6 December, 3 kW was routed to Zvezda for the first time, bringing its total to 6-7 kW. When STS-97 departed, the wings were providing an average of 13 kW to the Station.

The third and final EVA, on 7 December, when Noriega and Tanner tensioned the slack starboard blankets, brought the total EVA time during STS-97 to 19 hr 20 min. Total EVA time outside the Station was now 88 hr 54 min (all EVAs are still from the Shuttle airlock, until the Russians attach their Docking Compartment in August and NASA the Joint Airlock in June).

The two crews did not meet until 8 December because the hatches had remained closed while the Shuttle operated at a lower air pressure for the EVAs. After swapping equipment and rubbish, *Endeavour* undocked at 19:13 UT on 9 December. With the new power supply, the Expedition-1 crew now had continuous access to Unity. Without power, they had not entered it for the first time until 3 December.

The crew celebrated Christmas by opening gifts delivered by Progress and STS-97.

Progress-M1-4, undocked on 1 December, had been commanded to a distance of 2300 km while controllers decided what to do with it. The failure of its Kurs automatic docking system prompted engineers to devise a software patch and test it out on 26 December. Progress brought itself to within 200 m of Zarya's nadir port, where Gidzenko took over manual control using the TORU system for the link-up. Rubbish and surplus items were loaded into Progress for incineration during its destructive reentry over the Pacific after undocking at 11.26 UT on 8 February 2001 to clear the way for STS-98.

STS-98 with Commander Ken Cockrell, Pilot Mark Polansky and Mission Specialists Bob

*Expedition-2 crew (from left): Voss, Usachev and Helms.*

*The Expedition-1 crew (in blue) greet their STS-98 visitors, 9 February.*

Curbeam, Marsha Ivins and Tom Jones docked with the Unity/PMA-3 nadir position at 16:51 UT on 9 February carrying the Station's first research module: the 13.38 t Destiny. In fact, Destiny is the core of the whole Station. At $1.4 billion it is the Station's single most expensive element, and its 13 computers are the command and control node for the complex. Its activation meant that Houston replaced Moscow as the lead control centre. Destiny added 110 m³ to the Station, increasing the living space by 41%, and giving it a larger volume than any space station in history. Station mass is now 100 t.

Ivins began the installation sequence, using the Shuttle's robotic arm to remove PMA-2 at 15:00 UT from Unity's end position to make room for Destiny. She latched it in a temporary position on the Z1 Truss. At 15:50 UT Jones and Curbeam began their EVA to work in tandem with Ivins. Jones provided her with visual cues as she moved the adapter to its temporary position, and Curbeam removed protective launch covers and disconnected power and cooling cables between Destiny and *Atlantis*. Ivins latched the arm onto Destiny at 17:23 UT and lifted the module from the Shuttle payload bay at 17:35 UT. High above the bay, she flipped it 180°, and at 18:57 UT Destiny was latched into position on the Station. A set of motorised bolts tightened to hold it permanently in place.

With Destiny secured, Jones and Curbeam began connecting electrical, data and cooling lines. While Curbeam was attaching a cooling line, a few frozen ammonia crystals leaked briefly. He remained in the Sun for half an hour to vaporise any crystals on his spacesuit while Jones brushed him off. They performed a partial pressurisation and venting of the Shuttle airlock to flush out any ammonia before a final repressurisation. As the airlock began exchanging air with the Shuttle cabin, Cockrell, Polansky and Ivins wore oxygen masks for about 20 minutes. In the end, no smell of ammonia was reported.

Do You Want to See the Space Station? Then go to *http://www.heavens-above.com/* and it will show you when the Space Station is next visible from your location.

At about 02:20 UT 11 February, Cockrell and Shepherd began remotely powering up key Destiny systems and cooling equipment, sending commands via a laptop computer. They were the first to enter Destiny, at 14:38 UT 11 February, to begin the day-long outfitting activities. This included the activation of air conditioners, fire extinguishers, computers, internal communications systems, electrical outlets, ventilation systems, alarm systems and the installation of the Atmospheric Revitalisation Rack (ARS), augmenting the Russian Vozdukh system in the Zvezda living quarters. Racks for tool and experiment stowage were also installed. Because of mass considerations, Destiny was launched with only five of its 24 racks installed. Destiny's first science rack – the Human Research Facility – came up on the next Shuttle visit. The module also carried only a basic set of software, to be upgraded in orbit.

By the time STS-98 departed, ground controllers declared Destiny to be in excellent shape. The only problem was a baulky pump in the ARS carbon dioxide removal system.

Jones and Curbeam made their second EVA on 12 February. Ivins used the Shuttle arm to move PMA-2 from its temporary Z1 position to Destiny's end port, with visual cues provided by Jones and Curbeam. It is now the primary docking port for Shuttle visits.

Jones and Curbeam installed insulating covers over the pins that had held Destiny in place during launch, attached a vent to part of the lab's air system, fixed wires, handrails and sockets on the exterior to help future spacewalkers, and attached a base for the Station's robotic arm, scheduled for launch in April.

They connected several computer and electrical cables between the docking port and Destiny, unveiled the lab's 51 cm-diameter, optical-quality window and attached an external shutter.

While the EVA was underway, ground controllers sent commands to begin spinning and testing the four large 6600 rpm Control Moment Gyroscopes in the P6 Truss section delivered by STS-92. They are operated by electronics inside Destiny. On 13 February, they took over control of the Station's orientation from the thrusters, conserving precious propellant. Only two are required for full control. Control was handed back and forth during the week as tests continued.

Jones and Curbeam performed their third EVA – and the 100th in US space history – on 14 February. They attached a backup S-band antenna to Z1, checked connections between Destiny and its docking port, deployed a cooling radiator on P6, inspected solar array connections, and tested the ability of a spacewalker to carry an immobile colleague back to the Shuttle airlock.

On the final day of docked operations, 15 February, the crews transferred 1.3 t of equipment and supplies into the Station, including water, food, spare parts, a spare Vozdukh carbon dioxide removal system for Zvezda, a spare computer, clothes and movies. Some 400 kg of rubbish – used batteries, packing materials, empty food containers and other items – was moved into *Atlantis*.

The Shuttle also gave the Station its fourth and final altitude boost, leaving it 381 km – 26 km higher than before the visit. *Atlantis* undocked 16:06 UT 16 February after 6 d 21 h 15 m. The hatches had been open for 63 h 9 m.

With a new Progress supply ferry due to arrive Zvezda's aft port, the Station crew had to board their Soyuz and move it to Zarya's nadir port. With Gidzenko at the controls, Soyuz-TM31 backed away 100 m from the Station at 10:06 UT 24 February and docked at 10:37 UT to Zarya. It was the first time since the crew's arrival last 2 November that the Station had been unoccupied. They had to spend the next several hours reopening the hatches and reactivating key environmental and communications systems that had been shut down in the unlikely event they had been unable to redock, forcing them to come home.

Progress-M44 automatically docked with Zvezda at 09:50 UT on 28 February, successfully using the Kurs approach system. Within 2 hours, the crew opened the hatches to unload its supplies, including clothing, spare parts, computers and office gear for this crew and their successors. ■

## ISS Milestones

20 Nov 1998: Zarya launch, first ISS element.

4 Dec 1998: STS-88/2A launch, docks Unity Node-1 with Zarya 7 Dec. First crew aboard ISS 10 Dec. 3 Shuttle EVAs made external connections.

27 May 1999: STS-96/2A.1 launch, docks with Unity/PMA-2 29 May carrying logistics in Spacehab module. Shuttle EVA installs 2 external cranes. Undocks 3 Jun.

19 May 2000: STS-101/2A.2a Atlantis launch, docks with Unity/PMA-2 21 May carrying supplies and to perform maintenance (including EVA 22 May from Shuttle). Undocks 26 May.

12 Jul 2000: Zvezda launch; Zarya/Unity docks with it 26 Jul.

6 Aug 2000: Progress-M1-3/1P launch, docks with Zvezda aft port 8 Aug carrying cargo/propellant. Undocks 1 Nov.

8 Sep 2000: STS-106/2A.2b Atlantis launch, docks with Unity/PMA-2 10 Sep carrying logistics in Spacehab module. Shuttle EVA makes Zvezda/ Zarya external connections. Undocks 17 Sep.

11 Oct 2000: STS-92/3A Discovery launch, docks with Unity/PMA-2 13 Oct. Attaches first Truss section (Z1, with CMGs and Ku-band comms system) to Unity zenith port 14 Oct. 4 Shuttle EVAs make Z1/Unity connections, attach PMA-3 to Unity nadir, and prepare for future attachments. Undocks 20 Oct.

31 Oct 2000: Soyuz-TM31 launch, Expedition-1 crew (Gidzenko, Shepherd, Krikalev) docks with Zvezda aft port 2 Nov.

16 Nov 2000: Progress-M1-4/2P launch, docks with Zarya nadir port 18 Nov carrying cargo/propellant. Undocks 1 Dec. Redocks 26 Dec, undocks 8 Feb 2001.

30 Nov 2000: STS-97/4A Endeavour launch, docks with Unity PMA-3 2 Dec. P6 Truss segment with solar arrays installed in 3 EVAs. Undocks 9 Dec.

7 Feb 2001: STS-98/5A Atlantis launch, docks with Unity PMA-3 9 Feb. US Destiny lab attached 10 Feb; PMA-2 moved from Unity nadir to Destiny forward. ISS attitude control transferred from Zvezda to Destiny. Undocks 16 Feb.

24 Feb 2001: Soyuz-TM31 moves from Zvezda aft port to Zarya nadir port.

26 Feb 2001: Progress-M44/3P launch, docks with Zvezda aft port 28 Feb carrying cargo/propellant.

8 Mar 2001: STS-102/5A.1 Discovery launch, docks with Destiny PMA-2 10 Mar. First MPLM (Leonardo) attached/detached Unity/PMA-3 nadir. Expedition-2 crew swaps with #1 crew. Undocks 19 Mar.

**Planned**

12 Apr 2001: Progress-M1-6/4P launch, docks with Zvezda aft port carrying cargo/propellant.

19 Apr 2001: STS-100/6A Endeavour launch, docks with Destiny/PMA-2. Second MPLM (Rafaello) attached/detached Unity/PMA-3 nadir, with racks/equipment for Destiny outfitting. UHF antenna and Canadian SSRMS Station robot arm installed.

30 Apr 2001: Soyuz-TM32 taxi flight. Docks with Zvezda aft port. Crew returns in TM31 from Zarya nadir, leaving TM32 as fresh return craft.

8 Jun 2001: STS-104/7A launch, docks with Destiny/PMA-2 18 May. Installs Joint Airlock and High Pressure Gas Assembly.

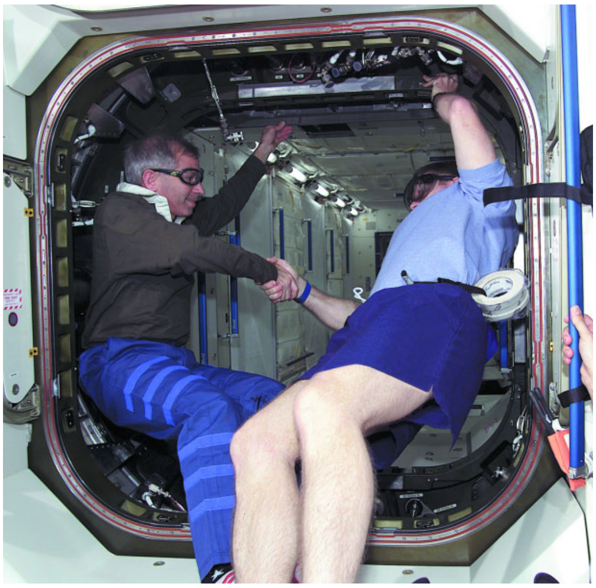
4 Jul 2001: Progress/5P launch, docks with Zvezda aft port carrying cargo/propellant.

12 Jul 2001: STS-105/7A.1 Endeavour launch, docks with Destiny/PMA-2. Third MPLM (Donatello) attached/detached Unity/PMA-3 nadir, with racks/equipment for Destiny outfitting. Expedition-3 crew (Culbertson, Dezhurov & Turin) swaps with Expedition-2.

25 Aug 2001: Russian docking compartment (DC-1) and Strela boom attached to Zvezda nadir port for Russian-based EVAs and Soyuz dockings.

6 Sep 2001: Progress/6P launch, docks with Zvezda aft port carrying cargo/propellant.

*Cockrell (left) and Shepherd make the first entrance into Destiny, on 11 February.*



# Recent & Relevant

## André-Deshays to Fly

ESA Astronaut Claudie André-Deshays began training on 22 January in Star City, Moscow for a Soyuz 'taxi' mission to the Space Station in October. The Soyuz escape craft are replaced every 6 months by a fresh vehicle piloted by a crew of two, leaving the third seat open for cargo or astronaut. André-Deshays will fly in the left-hand seat as an engineer. The 10-day flight, organised by CNES, offers 8 days aboard the Station before returning in the older Soyuz. CNES is developing a research programme using a 100 kg payload delivered by Progress and Soyuz, and shared between CNES, DLR and ESA. ■

*Claudie André-Deshays prepares for EVA training at Star City.*

## ESA Capcom

Gerhard Thiele became the first ESA Astronaut to work as a Capcom during a Shuttle mission, handling voice communications between controllers in Houston and the STS-98 crew in orbit in February. In March, he played a similar role during the STS-102 mission. ■

## Staying Healthy

ESA's initiative to develop an exercise device that combats muscle wasting on long-duration space missions has now been approved. The new ESA device, based on the patent of inventor Prof. Per Tesch, who recently visited ESTEC, uses the 'Flywheel for Resistive Exercise'. The approach is simple: the user pulls on a cord attached to two large flywheels, and then resists as the cord rewinds on the spinning wheels. This is the most efficient system yet available, in terms of effectiveness and resources needed, for maintaining astronauts' muscle mass. Counteracting wastage is trickier than might be expected – despite two decades of long flights, no-one has yet come up with a truly efficient method.

The new device is attractive in several ways: a vast amount of research provides a high level of confidence in the technology; it can be used in many Station locations; a wide range of muscles benefits from it and the effect is high quality. Perhaps most importantly, the high efficiency means that it leaves ample time for crew training on either the bicycle ergometer or treadmill for keeping the circulatory system healthy. ■

*ESA's exerciser is destined for the Station in 2003.*

## Bed-rest in 2001

ESA, together with CNES, DLR and NASDA, will make two European bed-rest studies in 2001 to support human physiology experiments in space, with an eye to long-duration travel such as Mars missions. These studies keep volunteers bed-ridden for long periods to simulate the effects of weightlessness on the human body.

The first study starts in April with eight subjects kept horizontal for 2 weeks at the DLR Institute for Aerospace Medicine in Cologne. Measurements will be taken before, during and after, focusing on the effect of weightlessness on food intake and metabolism. The study covers four phases, each representing one of the possible combinations of position control (horizontal vs. upright) and dietary control (normal and under-nutrition).

The second study begins in August, with 25 subjects spending 4 months at the Institute of Space Medicine in Toulouse. This study focuses on physical deconditioning, muscle atrophy and bone-mass loss as a result of long-duration inactivity, as well as testing the effectiveness of some drugs and exercise techniques.

Finding volunteers is not difficult – more than 7000 applied!

Both studies are important for health care on Earth, including problems related to ageing (osteoporosis, nutritional problems) as well as longer immobility due to handicap or prolonged illness (cardiovascular problems, muscle atrophy). The clinical implications will be strongly pursued by ESA and the scientists involved, and further ESA follow-on studies are planned. ■

## ISS Advanced Training

The first ESA astronauts will begin ISS Advanced Training in Houston on 2 April to become eligible as Station residents once assembly of the complex is completed in 2006. The International Partners agreed in November 2000 that up to four ESA astronauts, three Japanese and a Canadian could take the 1-year course.

The training is organised in blocks of several weeks and located at the various Partner training sites, spread over 18 months. In between the blocks and after completion of this training, refresher lessons will maintain the astronauts' proficiency. Once assigned to a specific Station mission ('increment') with US and Russian colleagues, an astronaut will then undertake Increment Training.

During the Station's current assembly phase, the first six prime crews were directly assigned to Increment Training with their backups. The back-up crews will in turn be assigned to the next six increments, starting with the 7th. This back-up training is equivalent to the ISS Advanced Training. When assembly is complete, the syllabus will normalise at Basic Training + Advanced Training + Increment Training. ■

## Maxus-4 Ready to Launch

ESA's Maxus-4 suborbital microgravity mission is scheduled for launch on 29 April from Esrange near Kiruna in northern Sweden. The flight up to 710 km will provide microgravity conditions of better than $10^{-4}$ *g* for about 12.5 minutes.

The 490 kg scientific payload comprises five autonomous modules with seven experiments from Belgium (1), France (1), Germany (3), Italy (1) and Sweden (1) in material science (3) and fluid physics (4). Two of the fluid physics experiments have similar set-ups to investigate surface-driven flows in a liquid bridge as a model of the floating zone crystal growth technique. The others will characterise aqueous and non-aqueous foams. The first materials science experiment will look at the initial crystallisation of silicalite-1. Two silicon-growth experiments will be performed in mono-ellipsoidal mirror furnaces. The first investigates how the Marangoni convection in the melt of the growing semiconductor can be suppressed by a rotating electromagnetic field. The second uses a piezoelectric oscillator to induce vibrations in the melt of the growing crystal to influence and control the segregation. ■

## First ESA Microgravity Payload aboard Station

*Typical APCF crystal growth reactors*

In July, on ISS assembly flight 7A.1 (STS-105), Space Shuttle *Discovery* will deliver ESA's first microgravity payload to the Space Station: the Advanced Protein Crystallisation Facility (APCF). APCF will be installed in the Shuttle middeck carrying seven experiments from Belgium, France, Germany, Italy and The Netherlands. After docking, the crew will transfer APCF's locker to an Express Rack inside the Destiny laboratory. It will be activated for automatic execution of protein crystal growth sequences in 38 individual reactors. After some 15 weeks, APCF will be deactivated and transferred into Shuttle *Endeavour* (STS-108/UF-1) in November for return to Earth.

APCF's flight is being made through an arrangement between Italy's space agency (ASI) and ESA. In a bilateral agreement with NASA, ASI has provided three Multi-Purpose Logistics Modules (MPLMs) to NASA, receiving early Station flight opportunities in return. ASI is providing the APCF flight opportunity as a special gesture to the EMIR-2 European Microgravity Research Programme.

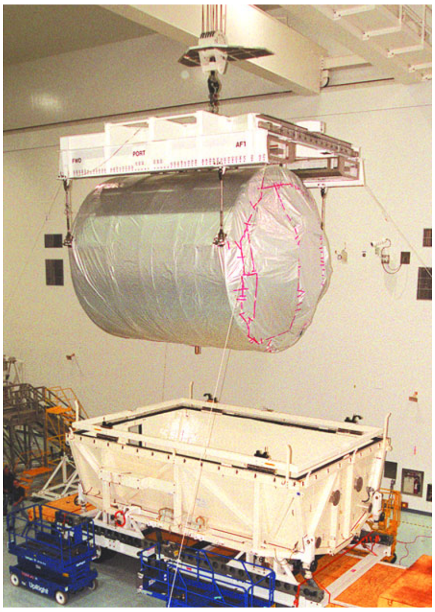
Shuttle *Endeavour* STS-108 will carry another ESA microgravity experiment on its 10-day flight to the Station. The materials science experiment on 'Weak Convection Influencing Radial Segregation' will be carried in a Get Away Special canister attached to the payload bay wall of *Endeavour*. ■

# Recent & Relevant

## Final MPLM Delivered

Italy's third and last Multi-Purpose Logistics Module (MPLM), Donatellom was delivered on 1 February to the Kennedy Space Center to begin preparations for ferrying hardware and supplies to the Space Station. MPLM is making a unique contribution to Station logistics because it is the only module capable of delivering complete payload racks. It is part of a bilateral arrangement between ASI and NASA, whereby ASI has exclusive access to certain Space Station utilisation rights in exchange for the supply of the three MPLMs to NASA.

ESA developed and delivered the Environmental Control and Life Support (ECLS) equipment for the MPLMs and Columbus, in exchange for which ASI provided the primary structures for both vehicles. In this way, each agency was relieved of developing significant portions of major subsystems, thereby saving tens of millions of Euros.



*MPLM Donatello arrives in the Space Station Processing Facility at the Kennedy Space Center.*

Details of the MPLM/ECLS can be found in ESA brochure BR-143 and at the website *http://esapub.esrin.esa.it/br/br143.htm*

Leonardo was delivered to KSC on 3 August 1998 for its debut in March, on Shuttle mission STS-102/5A.1. Raffaello arrived on 2 August 1999, and will fly on STS-100/6A in April. Donatello is aiming to debut on STS-105/7A.1 in July.

## MFC Status

ESA's Microgravity Facilities for Columbus (MFC) programme is now well into its Engineering Model (EM) phase. Testing of Biolab's EM is underway. A crew evaluation by ESA Astronauts Claudie André-Deshays and Pedro Duque confirmed that the facility offers easy operation and maintenance in orbit.

The Fluid Science Laboratory EM is well advanced and integration is almost complete. Recently, ESA concluded an agreement with the Canadian Space Agency to receive a Microgravity Vibration Isolation System (MVIS) to maintain a good microgravity environment aboard the Station, as requested by European scientists.

The Materials Science Laboratory will be integrated into the NASA Materials Science Research Rack-1 for launch on UF-3 in 2004. EM integration is almost complete. A crew evaluation confirmed the design for the on-orbit exchange of furnaces.

Development of the European Physiology Modules began after the other facilities, but bread-boards have now been manufactured.

## ESA's New ISS Exploitation Preparation Department

As Head of MSM's new ISS Exploitation Preparation Department at ESTEC, Jochen Graf has taken over elements of the responsibilities of Frank Longhurst, the former Head of the Manned Spaceflight Department. Since 1 October 2000, Jochen's responsibilities cover all the tasks leading to the regular, continuous use of ESA's contribution to the Space Station, development of the European Control Centres and Trainers, the preparation of flight operations and related activities, and engineering support for DMS-R and ERA. In addition, his department is initiating commercialisation activities for the Station. The study activities for future developments in manned spaceflight also reside within this department.

After studying electrical engineering in Berlin, Germany, Jochen began his professional career in 1966 with Siemens (Berlin), followed by 4 years with Ampex (California). He entered the management field as Project Manager for Data Management Systems in Medicine with GSF (Munich), before joining ESA in Noordwijk in 1974. He was initially responsible for Spacelab flight operations, a position later expanded to cover ground operations and software. In 1985, he joined the early management team for the ISS. His Division covered system definition, operations and software tasks. With the introduction of Russia into the Space Station programme, he became additionally responsible for the development of the Data Management System for the Russian Zvezda module.

Over the last 5 years, he has built up extensive experience in negotiating with the management teams of the Russian partner at agency and industry level. This included the conclusion of a long-term cooperative agreement on integration of ESA's Automated Transfer Vehicle with the Russian Segment and management of its initial implementation.

# Mission Accomplished

## Final Report on the Atmospheric Reentry Demonstrator

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### Introduction

ESA's Atmospheric Reentry Demonstrator (ARD) was a major European step towards future space transportation vehicles. For the first time, Europe flew a complete space mission – launching a vehicle into space and recovering it safely. ARD was launched on 21 October 1998 aboard Ariane-503, reaching a maximum suborbital altitude of 830 km before splashing down in the Pacific Ocean within 5 km of target.

During the mission, critical data such as pressure, temperature and vibration were recorded from more than 200 sensors distributed throughout the vehicle. The measurements were stored on two recorders as well as being transmitted to ground (Libreville in Gabon) and airborne (ARIA 1 and 2 aircraft) stations after Ariane separation and from before reentry through to landing. ARD was recovered by the French Navy and returned to prime contractor Aerospatiale in Bordeaux for detailed inspection.

ARD's main objectives were to:

- test and qualify reentry technologies and flight control algorithms under actual flight conditions,
- obtain inflight validation of design concepts, hardware and system capability to manage compromises between various technologies,
- validate aerothermodynamic predictions,
- qualify the design and the materials of the thermal protection system,
- assess the performances of the navigation, guidance and control system,
- assess the performances of the parachute and recovery system,
- study radio communications during reentry,
- to demonstrate industrial capability within a tight schedule and limited budget.

The preliminary post-flight analysis showed that everything worked well and identified the first differences between the predicted values and the flight data on the reentry onset, aerodynamic trim and side-slip angles, roll and drag commands, heating rates, high-altitude plasma frequencies, attitude control system propellant consumption and parachute opening loads.

*ARD was a major step towards future space transporation vehicles...*

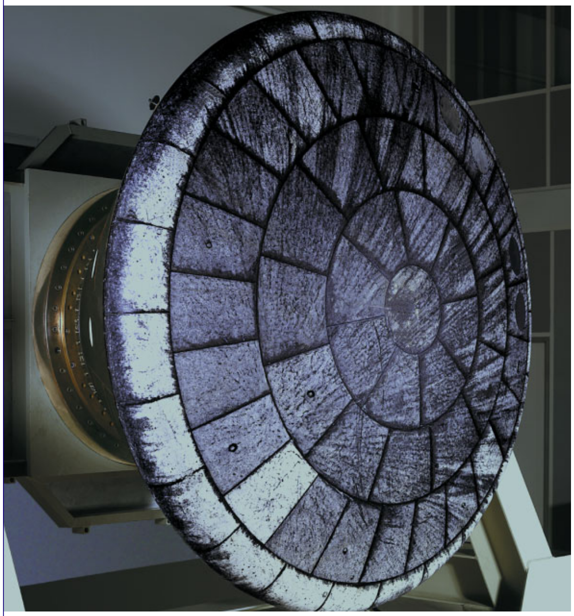
The trajectory prediction was based on estimated injection parameters from Ariane-5, with a conservative approach towards the heating rates. The first step of the analysis was therefore to use the actual flight parameters to rebuild the trajectory model as input for further detailed analysis. After that, the pre-flight prediction was updated for each technical discipline and then compared with the flight data.

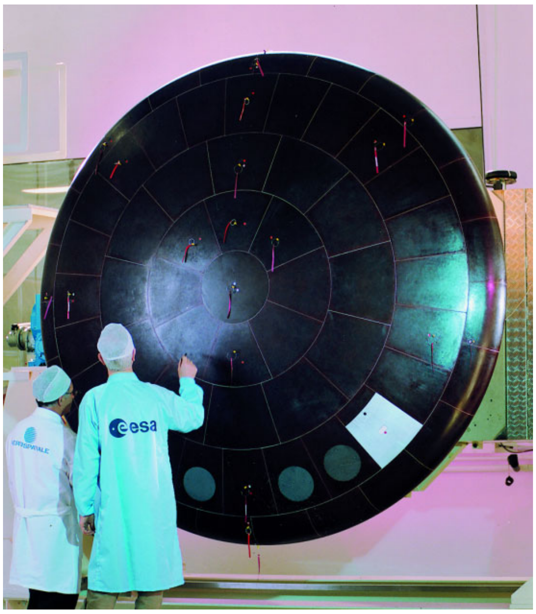
The more detailed analysis aimed at understanding the deviations in detail as well as to update the simulation/prediction tools. A final rerun of those tools was performed to validate the modifications.

### Aerodynamics/aerothermodynamics

ARD's hypersonic trim behaviour was consistent with a centre of gravity offset of 3-4 mm, explained by propellant consumption and heatshield pyrolysis. The systematic flight data analysis of the relative pressure data concluded that real-gas effects were also observed below Mach 10, and this was confirmed by additional Computational Fluid Dynamics (CFD) analysis.

The heating rates were difficult to assess because a thermocouple just below ARD's skin failed to return data in the 700-800°C range.





*ARD's heatshield before (right) and after the flight.*

However, the predicted peak heating rates were coherent with the flight data when chemical equilibrium is assumed. For the low heating rates, non-catalytic predictions were confirmed by flight data. These trends have been well reproduced by CFD/engineering methods. The low catalytic effects at high altitude were confirmed, whereas the pyrolysis effects close to peak heating inhibited the low catalytic behaviour, and resulted in heating rates close to chemical equilibrium conditions.

ARD's rear cone section provided another surprise: the overheating could not be reproduced by the current CFD analysis. The cause might be the effects of air thermochemistry, or there might have been an intermediate regime between the laminar and turbulent flows that is incorrectly described by current turbulence models.

### Thermal Protection System (TPS)

All TPS materials were carefully inspected, demounted and then mechanically tested. Finally, temperature measurements were analysed and compared with the design loads.

The main heat-shield material, Aleastrasil, confirmed the low surface erosion (0.1-0.3 mm) and enabled an update to the thermal properties data set, helping to reconstruct the thermal flux history. The conical body materials samples – Flexible External Insulation (FEI) and Carbon Silicon Carbide (C/SiC) – showed no flight degradation (no surface contamination through the ablative Aleastrasil or sea water impact). The thermal loads on ARD's leeward side were significantly lower than expected and well below FEI's limit; C/SiC's maximum of 940°C meant that the samples were not fully tested. The FEI suffered severe damage during recovery operations and demonstrated that special precautions (e.g. rigid covers) are necessary. There was no damage to the C/SiC samples themselves or to the attachment bolts from launch and landing stresses. The surface morphology and oxidation-protection layers were unchanged. ARD provided only a limited demonstration of FEI reusability because capsules naturally suffer more severe landing conditions than winged vehicles.

### Guidance, navigation and control

The recorded Inertial Measurement Unit (IMU) and radar data were carefully examined to build the reference trajectory. The performance of ARD's inertial navigation was rather good and the orbit injection errors were less than predicted and within the 1-sigma value.

It was found that an attitude offset (time-shifting of bank angle manoeuvre and a higher bank angle value) appeared with a higher load factor. These discrepancies can be explained by uncertainties in the atmospheric density model and in the Mass Centre of gravity and Inertial (MCI) model. After updating these models, the centre of gravity location and the normal and axial force coefficients were found to be coherent with the flight data.

The propulsion analysis revealed higher consumption than expected because of the centre of gravity offset, which required increased thruster firings during reentry in order to reduce the range and to compensate for wind perturbation. Most of the velocity (hence position) error was seen in the altitude range of 12-11 km, where there were large uncertainties in the north-south wind gradients. Improving the atmospheric model (particularly the density) is deemed necessary.

### Communications and plasma

The communications and Global Positioning Satellite (GPS) data showed a very sensitive receiver. The GPS data covered the launch, orbital and reentry phases. Inflight validation of the new 'code-only' mode (developed to enhance fast acquisition and robust tracking) was successful. Even ARD's rotation under the parachute was clearly seen in the GPS data.

The GPS data contributed significantly to analysing the formation of plasma during reentry. A minimum of nine geometrically distributed GPS satellites were permanently tracked and provided estimates of volumetric attenuation with a minimum sampling of 1 Hz and low-noise measurements. The analysis showed:

- highly asymmetrical attenuation effects, of 180-300 s duration,
- signals from the forward satellites are lost first and reappear last,
- partial reacquisition of GPS signals was observed.

Plasma analysis was divided into:

*Phase A:* axisymmetric calculations around a windward equivalent geometry in order to select the thermochemical modelling to be used for 3-D calculations,

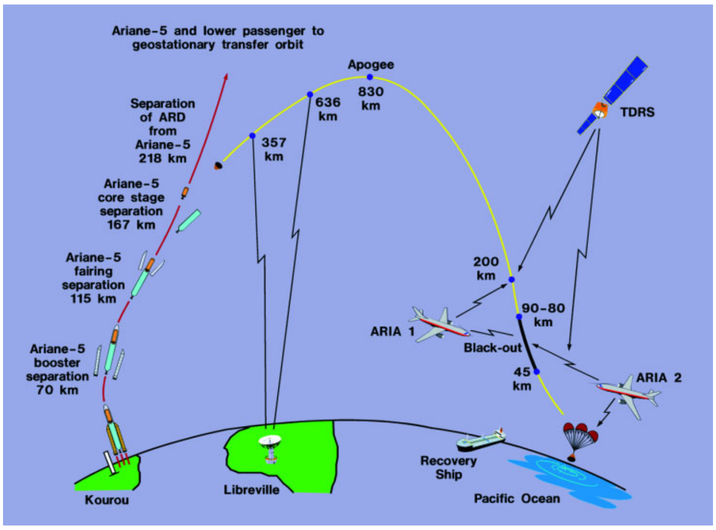
*Phase B:* 3-D calculations at three altitudes with comparisons between calculations and measurements on plasma frequencies at the reflectometer position and plasma attenuations of TDRS and GPS links.

There was relatively good agreement between the calculations and measurements at altitudes of 85 km and 46 km. The calculated plasma frequencies and TDRS link attenuations were clearly greater than those measured at an altitude of 61.5 km.

The plasma effect on radio links is perfectly correlated with the frequency (L & S-bands).

*ARD's predicted flight events*

| EVENT | PREDICTION (time from H0) | FLIGHT Measurement (time from H0) |
|---|---|---|
| AR-5 separation | 00:12:00/218 km | 00:12:00/216 km |
| Injection orbit (semi-major axis/inc.) | 6798.5 km<br>5.753° | 6802.4 km<br>5.754° |
| Libreville visibility | 00:17:09 - 00:27:39 | 00:17:38 - 00:29:20 |
| TDRS signal received | 1:08:34 | 1:09:10 |
| ARIA 1 visibility | 1:15:42 - 1:20:30 | 1:15:34 - 1:23:25 |
| Start of reentry (120 km) | 1:18:58 | 1:19:06<br>(longitude shift: 60 km) |
| Acceleration (max.) | 3.2 *g* | 3.7 *g* |
| Trim | 22° | 20° |
| Roll angle command (max.) | 105° | 110° |
| Blackout | 90 - 42 km | 90 - 43 km |
| Crossrange | 68 km | 67 km |
| ARIA 2 visibility | 1:22:05 | 1:25:02 |
| Parachute opening | 1:28:14 / 14 km | 1:28:00 / 14 km<br>horizontal accuracy 3 km |
| Splashdown | 1:42:55<br>sink rate : 6.7 m/s<br>impact: 7 *g* | 1:41:19<br>sink rate: 7 m/s<br>impact: 7.3 *g*<br>accuracy: 4.9 km |
| End of mission | 1:47:55 | 1:46:23 |




*ARD major events: predicted values compared with the post-flight reconstruction. H0 is the time of Ariane-5 main engine ignition. Times are in h:min:s*

As a consequence of the communications analysis, the following additional instrumentation is recommended :

- windward and leeward reflectometers to measure longitudinal and circumferencial plasma evolution,
- multi-frequency reflectometers for obtaining partial plasma frequency profiles and collisional frequencies or plasma thickness measurements.

## Parachutes

The effect of the overall study approach for the parachutes led to the following basic results.

*Inflation loads:* drag area growth formulae are adequate.

*Descent rate - drag area calibration:* 80% is the appropriate scaling to be applied for the 20% porosity conical ribbon drogue chute efficiency in capsule wake fields.

*Deployment analysis:* simplified 1-D Codes are fully applicable for the deployment analyses. A 10% safety factor should be used for estimating stretch-velocity (and snatch force).

*Attitude dynamics:* suitability of the simulator for stability prediction in 2-D (pitch) analysis; unsuitability of the simulator for complete 3-D attitude dynamics analyses.

Major simulator improvements required include:

- dynamic tests of suspension lines, characterisation of non-linearity and viscoelasticity have to be improved,
- parachute aerodynamics,
- detailed model of attachments, including characterisation of the stiction-friction at swivel axes.

## Lessons Learned and Conclusions

ARD's maiden flight was, as Europe's first step in reentry technology, a total success. Nevertheless, the detailed 'autopsy' shows that complete mastery of reentry is still a challenge and should include vehicles of different shapes and adoption of post-flight analysis recommendations. Telemetry recording is critical for understanding the reentry events. The impact of recovery operations must not be under-estimated.

Experimental flight vehicles are critical for understanding the reentry process. ARD was the first step and future tests such as X-38/V201 will build towards future space transportation systems.

For further technical details, readers can consult the ARD post-flight ftp server: *ftp.estec.esa.nl; userid: ard-pfas; password : ard p0st* ('zero' not 'o')' ■

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